GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT INITIATION

Date: 7/14/80

Project Title: Ice/Frost Detection Using Millimeter Wave Radiometry

Project No: A-2668

Project Director: Mr. J.A. Gagliano

Sponsor: NASA; Marshall Space Flight Center, Alabama 35812

8/31/81
~~7/1/81~~
~~4/1/81~~

Agreement Period: From 5/28/80 Until ~~9/28/80~~ (Contract Period)

Type Agreement: Contract No. NAS8-33800

Amount: $36,137

Reports Required: Monthly Progress Reports; Final Technical Report

Sponsor Contact Person (s):

Technical Matters

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Contractual Matters
(thru OCA)

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Defense Priority Rating: DO-C9 under DMS Reg. 1

Assigned to: EML/RSD (School/Laboratory)

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8R-281

GEORGIA INSTITUTE OF TECHNOLOGY — OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION SHEET

Date 9/22/81

Project Title: Ice/Frost Detection Using Millimeter Wave Radiometry

Project No: A-2668

Project Director: Mr. J. A. Gagliano

Sponsor: NASA; Marshall Space Flight Center, AL 35812

Effective Termination Date: 10/31/81

Clearance of Accounting Charges: 10/31/81

Grant/Contract Closeout Actions Remaining:

- [x] Final Invoice and Closing Documents
- [ ] Final Fiscal Report
- [x] Final Report of Inventions
- [x] Govt. Property Inventory & Related Certificate
- [ ] Classified Material Certificate
- [ ] Other ____________

Assigned to: EML/RSD (School/Laboratory)

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FORM OCA 10:781

WORK PERFORMED DURING THIS PERIOD

Georgia Tech personnel visited NASA/MSFC to review the requirements for the new program "Ice/Frost Detection Using Millimeter Wave Radiometry". This included discussions with Ed Gleason, Farouk Huneide, and Rick Bachtel regarding the test plan for the target measurements to be performed at Georgia Tech. A visit was made to a MSFC test site to view an existing target test environment chamber previously used by NASA.

Parts procurement for the Georgia Tech designed target chamber was completed during this period. Assembly of the chamber with the exception of the spray-on-foam insulation (SOFI) target panels was completed. Figure 1 is a photograph of the target chamber designed for the ice/frost detector measurements. The 1/2 inch thick aluminum plate mounted within the enclosure serves as a reservoir for the liquid nitrogen used to reduce the temperature to below freezing. The front plexiglas door is hinged at the bottom and latched at the top to provide quick access to the SOFI target which will be mounted to the aluminum reservoir shown. The 8 inch air ducts located at the top of the enclosure channel cooled air from an adjacent 11,500 BTU portable air conditioning unit. The purpose of the air conditioner is to reduce the amount of moisture forming on the inside of the test enclosure. Horizontal pivot bearings on each side of the enclosure allow the target deflection angle to be varied during the measurements. The test enclosure allows for the mounting of a single 3 foot by 3 foot SOFI target.

Georgia Tech has arranged for a local vendor to perform the spray-on-foam insulation on the 1/8 inch thick aluminum target plates being supplied by NASA/MSFC. The SOFI thicknesses chosen are 1/4 inch, 1/2 inch, and 3/4 inch on the three plates to be supplied.

Work continues on reconfiguring the 95 GHz radiometer for the ice/frost detection measurements. This includes routine maintenance and alignment procedures on the radiometer hardware and the debugging of new software programs incorporated for these measurements. Development of the pixel temperature software is progressing.

A test site adjacent to the Electronics Research Building (ERB) on Georgia Tech's campus has been selected. This site allows for a clear viewing distance of 200 feet maximum to the target sample. The radiometer can be secured within the ERB whenever the system is not operating.

PROBLEMS ENCOUNTERED DURING THIS PERIOD

During the process of aligning the radiometer during reconfiguration, a 95 GHz Gunn diode oscillator (GDO) quit working. A back-up GDO was found and installed immediately. However the failed device has been returned to the vendor for repair cost and time estimates. In order to prevent measurement shutdown during field operation, it is important to have a back-up GDO available since it is a critical part of the radiometer.

WORK TO BE PERFORMED NEXT PERIOD

Plans call for transporting the 95 GHz radiometer and the target sample enclosure to the test site in preparation for preliminary measurements. Check-out of the pixel temperature software is planned during this period. A video multiplier circuit will be designed and installed to provide a means of correlating the horizontal and vertical polarization channels data. Such information should be useful in the distinction of ice from frost forming on the target sample. The target samples will be foam sprayed by North Bros. Co. Insulation of Atlanta, Ga. upon arrival of the aluminum back plates from NASA/MSFC. The real-time temperature indicator panel will be designed and fabricated so that the temperature on the surface of the SOFI sample can be monitored.

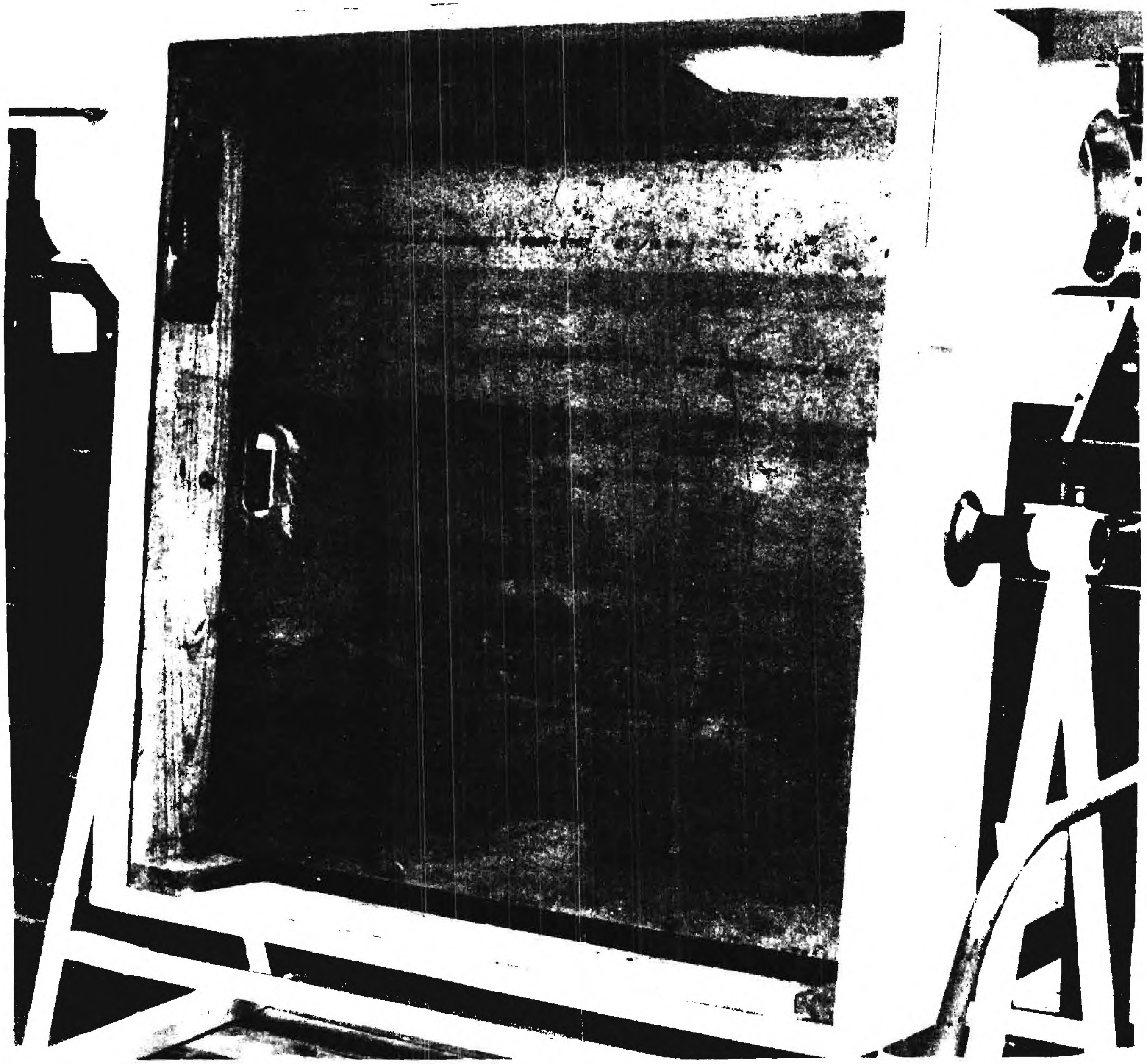

Figure 1. Ice/Frost Detector Test Enclosure for External Tank Target Samples

Cost Information

The following charges have been incurred against the contract during period 1 June through 30 June 1980.

	Expended	Encumbered
Personal Services (PS)	$ 3,385.27	$ -0-
Materials and Supplies	210.20	439.69
Travel	113.81	-0-
Overhead (@ 76% of PS)	2,572.80	-0-
Retirement (@ 10.51% of PS)	339.30	-0-
TOTAL	$ 6,621.38	$ 439.69

The breakdown of personal services is as follows:

	Dollars	Approximate Man Hours
Principal Research Scientists/Engineers	$ -0-	-0-
Senior Research Scientists/Engineers	1,030.77	60
Research Scientists II/Engineers II	1,095.86	82
Research Scientists I/Engineers I	815.88	75
Technicians/Draftsmen	245.15	30
Students	156.80	27
Secretarial/Clerical/Other	40.81	7
TOTAL	$3,385.27	281

The current financial status of the contract is as follows:

	s	Expended	Free Balance
Personal	0	$ 3,385.27	$ 14,003.73
Materials	0	210.20	2,555.11
Travel ar	0	113.81	386.19
Computer		-0-	-0-
Overhead	)	2,572.80	10,643.20
Retiremen	)	339.30	1,487.70
Encumber-		439.69	-0-
FUNDING	)	$ 7,061.07	$ 29,075.93

Based on [illegible] d equivalent man hours are sufficient [illegible] y 19 % of the proposed task has been [illegible]

H-[illegible]

Monthly Progress Report No. 2

Report Period

1 July through 31 July 1980

Report Prepared

August 26, 1980

ICE/FROST DETECTION USING MILLIMETER WAVE RADIOMETRY

J.A. Gagliano
J. M. Newton

Contract No. NAS8-33800

Project No. A-2668

Prepared for

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Prepared by

Engineering Experiment Station
Georgia Institute of Technology
Atlanta, Georgia 30332

Cost Information

The following charges have been incurred against the contract during period 1 July through 31 July 1980.

	Expended	Encumbered
Personal Services (PS)	$ 8,743.58	$ -0-
Materials and Supplies	1,445.25	1,167.50
Travel	-0-	-0-
Overhead (@ 76% of PS)	6,382.82	-0-
Retirement (@ 10.51% of PS)	749.43	-0-
TOTAL	$17,321.08	$1,167.50

The breakdown of personal services is as follows:

	Dollars	Approximate Man Hours
Principal Research Scientists/Engineers	$ 104.99	4
Senior Research Scientists/Engineers	1,836.83	95
Research Scientists II/Engineers II	1,306.11	85
Research Scientists I/Engineers I	3,339.82	272
Technicians/Draftsmen	86.56	10
Students	1,969.80	352
Secretarial/Clerical/Other	99.47	15
TOTAL	$8,743.58	833

The current financial status of the contract is as follows:

	Budget As Proposed	Expended	Free Balance
Personal Services (PS)	$17,389.00	$12,128.85	$ 5,260.15
Materials and Supplies	3,705.00	1,655.45	882.05
Travel and Shipping	-0-	113.81	(113.81)
Computer	-0-	-0-	-0-
Overhead	13,216.00	8,955.62	4,260.38
Retirement	1,827.00	1,088.73	738.27
Encumbered	-0-	1,167.50	-0-
FUNDING	$36,137.00	$25,109.96	$11,027.04

Based on present full funding, the funding and equivalent man hours are sufficient to complete the task. Approximately 69 % of the proposed task has been completed.

Work Performed During This Period

Pixel temperature software development was completed and implemented into the data analysis program. The printed information available through the data analysis program can be separated into the following three categories:

1) Header Information - This is a listing of the first record of the file. It contains the operator entered scene conditions (weather, date, target type, etc.); the scan parameters (coordinates of center, top center, and left center, along with raster dimensions); and the lens losses for each channel. The header information is always listed for each file analyzed. An example is shown in Figure 1.

2) Calibration Data - The printed calibration data as shown in Figure 2 is computed from the binary calibration data stored on tape. The information is given both in volts and in degrees K for all eight channels for each calibration load, along with the corresponding gains and offsets. All thermistor values are also given as are the mixer bias currents and the cold load thermocouple temperature. The first calibration data set is always given, while the other calibrations can be listed as an option.

3) Scan Pixel Data - An example of the scan pixel data for a single channel is shown in Figure 3. The maximum and minimum pixel temperatures are always given while the individual pixel temperatures are available as an option. A single channel is analyzed during each "pass" of the analysis program. The channels can be chosen in any order. The pixel temperatures can be left uncorrected or corrected for lens losses. The pixel temperatures can be absolute (in degrees K) or relative to the "current" (at the time of the scan) sky conditions (in degrees K). The pixel temperatures can be determined based only on the initial calibration values or based on the most

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0016
GEORGIA TECH MMW PASSIVE TARGET SIGNATURE MEASUREMENTS RADIOMETER VERSION 3.3

RUN NUMBER =0016
DATE AND TIME =(DDMMYYXXXX)1508801625
PERCENT CLOUD COVER =099
GROUND CONDITION =DRY,SUNLIGHT
TEMPERATURE IN DEGREES C=031
PERCENT HUMIDITY =050
TARGET TYPE =DRY
ADDITIONAL COMMENT=NOFOAM,NOPLEXIG
NOMINAL DEPRESSION ANGLE=000
TARGET ASPECT ANGLE =045
TARGET RANGE =200
```

Scene Conditions

```
T0 =181.0
A0 =255.0
TCT =180.4
TCP =255.0
CLT =181.1
CLP =255.6
MAX LINES =011
MAX PIXELS =011
```

Scan Parameters

```
LOSS 0= 1.3978
LOSS 1= 1.3975
LOSS 2= 1.5279
LOSS 3= 1.5495
LOSS 4= 1.09[illegible]7
LOSS 5= 1.10[illegible]4
LOSS 6= 1.17[illegible]1
LOSS 7= 1.0000
```

Lens Losses

Figure 1. Header Information.

RADIOMETER VALUES:

	CH#0	CH#1	CH#2	CH#3	CH#4	CH#5	CH#6	CH#7
SKY (VOLTS) :	6.46	6.78	6.51	7.05	9.62	9.66	7.67	0.00
HOT (VOLTS) :	0.50	0.52	1.26	1.42	1.00	1.18	0.97	0.00
COLD (VOLTS) :	7.85	8.28	7.70	8.34	8.57	8.63	6.87	0.00
DICKE (VOLTS) :	1.21	1.25	1.89	2.08	2.11	2.24	1.52	0.00
GAIN (DEG/VOLT):	-35.00	-33.19	-39.99	-37.21	-34.03	-34.53	-43.62	1.00
OFFSET (DEG K) :	84.38	84.29	117.65	119.84	101.18	107.67	109.36	66.86
SKY (DEG K) :	130.95	132.09	130.06	130.29	46.58	47.06	47.56	339.86
HOT (DEG K) :	339.86	339.86	339.86	339.86	339.86	339.86	339.86	339.86
COLD (DEG K) :	82.40	82.40	82.40	82.40	82.40	82.40	82.40	339.86
DICKE (DEG K) :	314.81	315.54	314.66	315.41	302.04	303.00	315.68	339.86
0 VOLTS=(DEG K):	357.38	357.29	390.65	392.84	374.18	380.67	382.36	339.86
10 VOLTS=(DG K):	*7.35	25.33	-9.31	20.69	33.86	35.34	-53.83	349.86

CALIBRATION VALUES: (VOLTS, DEGREES C)

HOT LOAD	=	3.31	66.86	DRY BULB	=	6.58	34.13
DICKE #1 (UPPER)	=	5.78	42.19	BOX INTERIOR	=	6.58	34.18
DICKE #2 (LOWER)	=	6.08	39.12	35 GHZ MIXER #1	=	6.21	37.80
35 GHZ GUNN	=	5.90	40.95	35 GHZ MIXER #2	=	10.00	0.00
95 GHZ GUNN	=	6.02	39.75	95 GHZ MIXER #1	=	10.00	0.00
95 GHZ ISOLATOR	=	6.29	37.06	95 GHZ MIXER #2	=	6.31	36.87
LARGE LENS	=	6.16	38.31	SPARE	=	10.00	0.00
WET BULB	=	10.00	0.00	SPARE	=	10.00	0.00

MIXER BIAS CURRENTS: (VOLTS, MICROAMPS)

MIXER BIAS #1	=	9.47	947.00	MIXER BIAS #3	=	6.97	1046.52
MIXER BIAS #2	=	9.42	942.12	MIXER BIAS #4	=	6.65	998.16

THERMOCOUPLE: (VOLTS, DEGREES C)

COLD LOAD	=	9.62	-190.59

Figure 2. Calibration Data.

CHANNEL 0 - MAX TEMP = 290.40 K, AT ROW 9 PIXEL 11 (1.74 VOLTS)

MIN TEMP = 153.47 K, AT ROW 5 PIXEL 4 (4.54 VOLTS)

	0	1	2	3	4	5	6	7	8	9	10	11	Mean 12	Std. Dev. 13
	1	266	263	266	265	264	263	269	266	271	277	279	268	5
	2	254	251	254	255	256	260	264	271	273	281	283	264	11
	3	232	225	230	228	227	226	235	247	254	261	276	240	17
	4	193	196	200	198	197	205	235	249	263	274	284	227	35
	5	196	185	172	153	158	160	196	221	245	259	273	202	42
	6	173	156	164	157	161	173	224	251	266	277	285	208	52
	7	220	193	188	183	178	182	221	230	255	269	285	219	37
	8	233	224	213	215	226	233	251	264	278	283	286	246	27
	9	268	261	258	250	255	254	267	269	278	279	290	266	12
	10	281	276	277	274	276	280	283	284	289	285	289	281	5
	11	0	0	0	0	0	285	0	0	0	0	0	285	0
Mean	12	232	223	222	218	220	229	244	255	267	275	283	242	0
Std. Dev.	13	36	39	40	43	43	43	27	19	13	8	5	0	38

Figure 3. Pixel Temperatures of Scanned Target.

recent calibration values if more than two calibrations were performed (the final calibration can be displayed, but is not used in pixel temperature calculations). Besides the pixel temperatures, the mean and standard deviation is given for each row, each column and for the overall raster. (Note: Temperatures of 0°K indicate pixels which are not sample points but merely "padding" when short rows are scanned. Their value does not affect any mean or standard deviation calculations.)

The 95 GHz radiometer and sample target enclosure were transported to the measurement site, and radiometric data were collected for several different target conditions: 1) dry foam; 2) ice covered foam; 3) bare metal; 4) ice covered metal. Some of these data are shown in Figures 4 through 9. Figures 4 through 6 depict a scan of a dry target and Figures 7 through 9 depict a scan of a target with ice and frost. The scan was set up with a bare metal plate approximately 1 meter to the right of the target as a reference. In all cases, the presence of the ice caused the apparent temperature of the target to increase. These data indicate that an ice covered target can be readily detected provided a reference target is available to be scanned concurrently with the primary target. This secondary target is necessary due to the random nature of the sky. Clouds with substantial amounts of water can drastically change the measured radiometric temperature of the target since the radiometer is actually looking into the sky via reflection from the target.

Other methods for compensating for sky variations, such as Dicke chopping on the sky, may be useful but have not been tried. Additional tests will be carried out to determine the feasibility of using some of these techniques.

Problems Encountered During This Period

Significant problems were encountered with the target chamber during attempts at ice formation. Filling the welded aluminum reservoir with liquid nitrogen causes the welds to crack and leak after just a few times. During the day, incident sunlight trapped by the plexiglass cover keeps the foam insulation too warm for ice to form. The plexiglass was replaced by 1 inch styrofoam insulation with good success.

Work To Be Performed Next Period

New methods of ice formation on the target will be attempted. Use of a large walk-in freezer is being investigated for this purpose.

More measurements will be made under a greater variety of conditions. Parameters to be varied include background, range, view angle, incident energy and precipitation.

0014

```
0014 MICOM PASSIVE TARGET SIGNATURE OEASUREMENTS RADIOMETER VERSION 3.3
DATE AND TIME =(DDMMYYXXXX)1508801247
PERCENT CLOUD COVER =060
GROUND CONDITION =DRY,SUNLIGHT
TEMPERATURE IN DEGREES C=032
PERCENT HUMIDITY =058
TARGET TYPE =DRY
ADDITIONAL COMMENT=1/4"FOAM,REF,NO

NOMINAL DEPRESSION ANGLE=000
TARGET ASPECT ANGLE =045
TARGET RANGE =200
T0 =181.1

A0 =256.1
TCT =180.4
TCP =256.1

CLT =181.2

CLP =257.7
MAX LINES =013
MAX PIXELS =031
LOSS 0= 1.3699
LOSS 1= 1.3829
LOSS 2= 1.5369
LOSS 3= 1.5448
LOSS 4= 1.0727
LOSS 5= 1.0767
LOSS 6= 1.1900
LOSS 7= 1.0000
```

RADIOMETER VALUES:

		CH#0	CH#1	CH#2	CH#3	CH#4	CH#5	CH#6	CH#7
SKY (VOLTS)	:	5.54	5.55	6.03	6.22	9.28	9.25	7.86	0.00
HOT (VOLTS)	:	0.46	0.51	1.21	1.37	0.69	0.92	0.76	0.00
COLD (VOLTS)	:	7.51	7.47	7.80	7.93	8.43	8.44	7.15	0.00
DICKE (VOLTS)	:	1.25	1.33	1.95	2.13	1.98	2.13	1.51	0.01
GAIN (DEG/VOLT)	:	-35.92	-33.36	-38.39	-38.53	-32.66	-33.60	-39.58	1.00
OFFSET (DEG K)	:	83.31	85.11	113.07	119.36	89.20	97.40	96.92	66.47
SKY (DEG K)	:	157.19	156.28	154.47	152.46	58.80	59.57	58.45	339.47
HOT (DEG K)	:	339.47	339.47	339.47	339.47	339.47	339.47	339.47	339.47
COLD (DEG K)	:	86.49	86.49	86.49	86.49	86.49	86.49	86.49	339.47
DICKE (DEG K)	:	311.13	309.72	310.87	310.10	297.26	298.60	309.89	339.48
0 VOLTS=(DEG K)	:	356.31	358.11	386.07	392.36	362.20	370.40	369.92	339.47
10 VOLTS=(DG K)	:	-2.89	-5.50	2.10	6.96	35.51	34.38	-25.93	349.47

CALIBRATION VALUES: (VOLTS, DEGREES C)

HOT LOAD	=	3.35	66.47	DRY BULB	=	6.29	37.02
DICKE #1 (UPPER)	=	6.25	37.41	BOX INTERIOR	=	6.30	36.97
DICKE #2 (LOWER)	=	6.38	36.16	35 GHZ MIXER #1	=	6.28	37.14
35 GHZ GUNN	=	5.93	40.61	35 GHZ MIXER #2	=	10.00	0.00
95 GHZ GUNN	=	5.93	40.61	95 GHZ MIXER #1	=	10.00	0.00
95 GHZ ISOLATOR	=	6.19	38.04	95 GHZ MIXER #2	=	6.28	37.19
LARGE LENS	=	5.76	42.34	SPARE	=	10.00	0.00
WET BULB	=	10.00	0.00	SPARE	=	10.00	0.00

MIXER BIAS CURRENTS: (VOLTS, MICROAMPS)

MIXER BIAS #1	=	9.45	945.78	MIXER BIAS #3	=	6.98	1047.98
MIXER BIAS #2	=	9.41	941.39	MIXER BIAS #4	=	6.64	997.06

THERMOCOUPLE: (VOLTS, DEGREES C)

COLD LOAD = 9.46 -186.50

Figure 4. Header and Initial Calibration for Dry Foam Target.

RADIOMETER VALUES: MIDLE OF SCAN CALIBRATION

		CH#0	CH#1	CH#2	CH#3	CH#4	CH#5	CH#6	CH#7
SKY (VOLTS)	:	6.33	6.55	6.56	6.96	9.60	9.63	7.80	0.61
HOT (VOLTS)	:	0.47	0.51	1.28	1.40	0.82	1.01	0.80	1.15
COLD (VOLTS)	:	7.52	7.66	7.68	7.98	8.52	8.56	7.05	0.60
DICKE (VOLTS)	:	1.26	1.30	1.98	2.12	2.06	2.21	1.49	0.71
GAIN (DEG/VOLT)	:	-35.74	-35.25	-39.20	-38.28	-32.71	-33.36	-40.32	454.55
OFFSET (DEG K)	:	83.46	84.52	115.84	120.11	93.29	100.25	98.94	-458.59
SKY (DEG K)	:	130.06	126.38	131.60	126.55	52.15	51.70	57.04	95.23
HOT (DEG K)	:	339.44	339.44	339.44	339.44	339.44	339.44	339.44	339.44
COLD (DEG K)	:	87.46	87.46	87.46	87.46	87.46	87.46	87.46	87.46
DICKE (DEG K)	:	311.08	311.64	311.20	311.67	298.70	299.44	311.48	137.42
0 VOLTS=(DEG K)	:	356.46	357.52	388.84	393.11	366.29	373.25	371.94	-185.59
10 VOLTS=(DG K)	:	-0.94	4.99	-3.19	10.23	39.13	39.64	-31.28	*******

CALIBRATION VALUES: (VOLTS, DEGREES C)

HOT LOAD	=	3.35	66.44	DRY BULB	=	6.25	37.46
DICKE #1 (UPPER)	=	6.20	37.94	BOX INTERIOR	=	6.26	37.36
DICKE #2 (LOWER)	=	6.34	36.55	35 GHZ MIXER #1	=	6.24	37.58
35 GHZ GUNN	=	5.89	41.07	35 GHZ MIXER #2	=	10.00	0.00
95 GHZ GUNN	=	5.89	61.05	95 GHZ MIXER #1	=	10.00	0.00
95 GHZ ISOLATOR	=	6.16	38.38	95 GHZ MIXER #2	=	6.26	37.38
LARGE LENS	=	5.73	42.63	SPARE	=	10.00	0.00
WET BULB	=	10.00	0.00	SPARE	=	10.00	0.00

MIXER BIAS CURRENTS: (VOLTS, MICROAMPS)

MIXER BIAS #1	=	9.45	945.05	MIXER BIAS #3	=	6.98	1047.25
MIXER BIAS #2	=	9.40	940.90	MIXER BIAS #4	=	6.64	997.43

THERMOCOUPLE: (VOLTS, DEGREES C)

COLD LOAD = 9.42 -185.53

RADIOMETER VALUES:

		CH#0	CH#1	CH#2	CH#3	CH#4	CH#5	CH#6	CH#7
SKY (VOLTS)	:	6.22	6.24	6.64	6.82	9.65	9.59	8.05	0.79
HOT (VOLTS)	:	0.47	0.54	1.25	1.43	0.84	1.03	0.81	1.06
COLD (VOLTS)	:	7.38	7.35	7.73	7.86	8.52	8.48	7.20	1.56
DICKE (VOLTS)	:	1.26	1.27	1.96	2.16	2.08	2.23	1.55	1.68
GAIN (DEG/VOLT)	:	-36.35	-36.92	-38.79	-39.04	-32.70	-33.74	-39.34	-509.57
OFFSET (DEG K)	:	83.88	86.67	115.36	122.44	94.12	101.51	98.56	611.61
SKY (DEG K)	:	130.46	129.22	130.45	128.82	51.21	50.61	54.66	480.18
HOT (DEG K)	:	339.56	339.56	339.56	339.56	339.56	339.56	339.56	339.56
COLD (DEG K)	:	88.20	88.20	88.20	88.20	88.20	88.20	88.20	88.20
DICKE (DEG K)	:	311.06	312.52	312.18	311.05	298.91	299.18	310.45	25.98
0 VOLTS=(DEG K)	:	356.88	359.67	388.36	395.44	367.12	374.51	371.56	884.61
10 VOLTS=(DG K)	:	-6.71	-9.53	0.36	4.95	40.03	37.02	-21.91	*******

CALIBRATION VALUES: (VOLTS, DEGREES C)

HOT LOAD	=	3.34	66.56	DRY BULB	=	6.22	37.77
DICKE #1 (UPPER)	=	6.16	38.36	BOX INTERIOR	=	6.22	37.70
DICKE #2 (LOWER)	=	6.31	36.87	35 GHZ MIXER #1	=	6.20	37.94
35 GHZ GUNN	=	5.86	41.34	35 GHZ MIXER #2	=	10.00	0.00
95 GHZ GUNN	=	5.84	41.53	95 GHZ MIXER #1	=	10.00	0.00
95 GHZ ISOLATOR	=	6.11	38.80	95 GHZ MIXER #2	=	6.21	37.80
LARGE LENS	=	5.67	43.27	SPARE	=	10.00	0.00
WET BULB	=	10.00	0.00	SPARE	=	10.00	0.00

MIXER BIAS CURRENTS: (VOLTS, MICROAMPS)

MIXER BIAS #1	=	9.44	944.81	MIXER BIAS #3	=	6.97	1046.88
MIXER BIAS #2	=	9.40	940.65	MIXER BIAS #4	=	6.64	997.43

THERMOCOUPLE: (VOLTS, DEGREES C)

COLD LOAD = 9.39 -184.79

Figure 5. Middle of Scan and End of Scan Calibrations.

CHANNEL 0 - MAX TEMP = 294.42 K: AT ROW 7 PIXEL 14 ([illegible] VOLTS)
MIN TEMP = 159.26 K: AT ROW 8 PIXEL 4 (4.28 VOLTS)
Run #14

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
1	289	280	290	283	290	285	288	288	289	290	290	289	288	288	292	290	285	281	278	278	277	282	280	283	281	283	280	278	281	277	276	284	4
2	289	286	285	283	283	285	286	286	287	288	287	289	287	292	291	284	271	271	268	266	263	264	264	261	264	264	267	264	263	266	274	277	10
3	280	280	276	275	276	270	274	272	276	284	287	290	288	291	288	291	276	272	260	254	241	248	238	237	237	234	232	236	242	248	260	265	20
4	264	*256	254	253	249	247	258	267	273	282	283	293	288	288	287	287	267	270	271	268	268	247	203	203	207	209	220	226	234	253	264	256	26
5	258	243	227	221	225	218	224	235	242	261	279	285	293	289	291	288	277	266	253	231	216	202	189	191	176	178	193	195	206	231	254	237	35
6	217	202	187	186	190	191	212	219	254	266	284	286	291	291	290	286	272	251	226	204	188	174	163	169	172	169	191	199	223	248	268	225	43
7	227	194	179	163	161	173	165	193	219	242	262	280	289	294	288	292	281	269	251	227	201	175	177	175	165	163	181	189	195	232	256	218	46
8	216	169	168	159	168	167	181	199	231	261	279	282	287	292	287	286	277	262	247	233	216	207	212	203	209	210	220	227	251	262	285	231	42
9	253	204	189	185	172	182	191	196	226	245	267	278	285	286	292	288	284	281	278	263	250	243	244	243	238	235	245	244	255	264	285	245	35
10	246	213	218	203	208	220	224	242	257	271	283	287	288	289	287	286	282	285	275	269	262	264	260	266	262	259	267	271	275	287	289	261	26
11	278	256	249	247	242	250	249	249	264	271	281	285	286	290	287	292	286	285	287	287	282	280	278	280	277	280	282	285	281	288	291	275	15
12	279	270	268	267	267	269	271	277	280	285	285	289	293	291	290	289	285	290	288	289	288	285	287	285	286	285	287	289	290	288	290	283	7
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	290	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	290	0
14	258	238	233	227	228	230	235	244	258	271	280	286	289	290	289	288	279	274	265	256	246	239	233	233	231	231	239	242	250	262	274	255	0
15	26	40	43	46	46	43	42	35	24	16	8	4	2	2	2	2	6	11	18	26	33	40	43	42	44	44	38	35	30	20	13	0	36

Figure 6. Pixel Temperatures for Scan, 95 GHz Vertically Polarized. Bare metal reference centered about Row 8, Pixel 4. Foam target centered about Row 7, Pixel 25.

0019
GEORGIA TECH MMW PASSIVE TARGET SIGNATURE MEASUREMENTS RADIOMETER VERSION 3.3
RUN NUMBER =0019
DATE AND TIME =(DDMMYYXXXX)1908801449
PERCENT CLOUD COVER =040
GROUND CONDITION =MOIST, SUNLIGHT
TEMPERATURE IN DEGREES C=028
PERCENT HUMIDITY =066
TARGET TYPE =FST
ADDITIONAL COMMENT=1/4"FM, 1"STFM, R
NOMINAL DEPRESSION ANGLE=000
TARGET ASPECT ANGLE =045
TARGET RANGE =200
T0 =181.0
A0 =259.3
TCT =180.2
TCP =259.3
CLT =181.1
CLP =260.8
MAX LINES =015
MAX PIXELS =029
LOSS 0= 1.4162
LOSS 1= 1.4131
LOSS 2= 1.5984
LOSS 3= 1.5852
LOSS 4= 1.0097
LOSS 5= 1.0000
LOSS 6= 1.2015
LOSS 7= 0.9083
RADIOMETER VALUES:

	CH#0	CH#1	CH#2	CH#3	CH#4	CH#5	CH#6	CH#7
SKY (VOLTS) :	5.95	6.01	7.01	6.86	9.22	9.86	8.22	0.00
HOT (VOLTS) :	0.44	0.50	1.15	1.38	0.43	0.68	0.73	0.00
COLD (VOLTS) :	7.05	7.04	8.11	7.88	8.21	8.79	7.31	0.00
DICKE (VOLTS) :	1.25	1.27	1.99	2.17	1.41	1.69	1.51	0.00
GAIN (DEG/VOLT):	-38.14	-38.58	-36.19	-38.79	-32.39	-31.07	-38.30	*******
OFFSET (DEG K) :	82.79	85.53	107.65	119.83	79.93	87.10	93.99	-186.14
SKY (DEG K) :	128.49	126.53	126.80	126.55	53.94	53.54	51.87	86.85
HOT (DEG K) :	338.93	338.93	338.93	338.93	338.93	338.93	338.93	338.93
COLD (DEG K) :	86.85	86.85	86.85	86.85	86.85	86.85	86.85	86.85
DICKE (DEG K) :	308.00	309.43	308.35	308.33	307.20	307.44	308.90	86.85
0 VOLTS=(DEG K):	355.79	358.53	380.65	392.83	352.93	360.10	366.99	86.85
10 VOLTS=(DG K):	-25.67	-27.35	18.71	4.91	28.94	49.37	-16.02	*******

CALIBRATION VALUES: (VOLTS, DEGREES C)

HOT LOAD	= 3.40	65.93	DRY BULB	=	6.64	33.57
DICKE #1 (UPPER)	= 6.48	35.16	BOX INTERIOR	=	6.57	34.26
DICKE #2 (LOWER)	= 6.64	33.52	35 GHZ MIXER #1	=	6.52	34.74
35 GHZ GUNN	= 6.16	38.36	35 GHZ MIXER #2	=	10.00	0.00
95 GHZ GUNN	= 6.17	38.24	95 GHZ MIXER #1	=	10.00	0.00
95 GHZ ISOLATOR	= 6.46	35.31	95 GHZ MIXER #2	=	6.59	34.01
LARGE LENS	= 6.40	35.94	SPARE	=	10.00	0.00
WET BULB	= 10.00	0.00	SPARE	=	10.00	0.00

MIXER BIAS CURRENTS: (VOLTS, MICROAMPS)

MIXER BIAS #1	= 9.53	953.11	MIXER BIAS #3	=	7.20	1080.58
MIXER BIAS #2	= 9.49	949.20	MIXER BIAS #4	=	6.78	1017.21

THERMOCOUPLE: (VOLTS, DEGREES C)

COLD LOAD = 9.44 -186.14

Figure 7. Header and Initial Calibration for Foam Target with Ice and Frost.

RADIOMETER VALUES:

	CH#0	CH#1	CH#2	CH#3	CH#4	CH#5	CH#6	CH#7
SKY (VOLTS) :	5.80	5.83	6.92	6.75	9.14	9.78	8.09	0.00
HOT (VOLTS) :	0.48	0.52	1.19	1.43	0.48	0.73	0.70	0.03
COLD (VOLTS) :	6.77	6.77	7.95	7.71	8.10	8.60	7.16	0.00
DICKE (VOLTS) :	1.24	1.28	2.02	2.17	1.42	1.72	1.48	0.00
GAIN (DEG/VOLT):	-39.78	-40.01	-36.98	-39.79	-32.81	-31.48	-38.71	*******
OFFSET (DEG K) :	85.46	87.23	110.20	123.08	81.91	89.34	93.45	-183.94
SKY (DEG K) :	127.43	126.87	127.07	127.15	54.92	54.15	53.22	89.05
HOT (DEG K) :	339.12	339.12	339.12	339.12	339.12	339.12	339.12	339.12
COLD (DEG K) :	89.05	89.05	89.05	89.05	89.05	89.05	89.05	89.05
DICKE (DEG K) :	309.01	308.73	308.33	309.40	308.04	308.14	308.78	89.05
0 VOLTS=(DEG K):	358.46	360.23	383.20	396.08	354.91	362.34	366.45	89.05
10 VOLTS=(DG K):	-39.38	-39.93	13.37	-1.91	26.79	47.54	-28.71	*******

CALIBRATION VALUES: (VOLTS, DEGREES C)

HOT LOAD	=	3.38	66.12	DRY BULB	=	6.63	33.65
DICKE #1 (UPPER)	=	6.44	35.55	BOX INTERIOR	=	6.47	35.21
DICKE #2 (LOWER)	=	6.60	33.94	35 GHZ MIXER #1	=	6.41	35.84
35 GHZ GUNN	=	6.07	39.29	35 GHZ MIXER #2	=	10.00	0.00
95 GHZ GUNN	=	6.08	39.19	95 GHZ MIXER #1	=	10.00	0.00
95 GHZ ISOLATOR	=	6.36	36.30	95 GHZ MIXER #2	=	6.40	35.16
LARGE LENS	=	6.29	37.09	SPARE	=	10.00	0.00
WET BULB	=	10.00	0.00	SPARE	=	10.00	0.00

MIXER BIAS CURRENTS: (VOLTS, MICROAMPS)

MIXER BIAS #1	=	9.52	952.62	MIXER BIAS #3	=	7.19	1079.12
MIXER BIAS #2	=	9.48	948.96	MIXER BIAS #4	=	6.77	1016.84

THERMOCOUPLE: (VOLTS, DEGREES C)

COLD LOAD = 9.35 -183.94

RADIOMETER VALUES:

	CH#0	CH#1	CH#2	CH#3	CH#4	CH#5	CH#6	CH#7
SKY (VOLTS) :	5.68	5.70	6.83	6.64	9.06	9.67	8.00	0.00
HOT (VOLTS) :	0.49	0.55	1.21	1.43	0.48	0.74	0.73	0.00
COLD (VOLTS) :	6.72	6.70	7.88	7.64	8.04	8.59	7.13	0.00
DICKE (VOLTS) :	1.22	1.30	1.98	2.17	1.40	1.71	1.49	0.00
GAIN (DEG/VOLT):	-40.23	-40.76	-37.60	-40.39	-33.11	-31.92	-39.20	1.00
OFFSET (DEG K) :	86.02	88.67	111.81	124.17	82.01	89.93	94.99	66.08
SKY (DEG K) :	130.10	129.05	127.75	128.70	54.72	54.06	54.26	339.08
HOT (DEG K) :	339.08	339.08	339.08	339.08	339.08	339.08	339.08	339.08
COLD (DEG K) :	88.44	88.44	88.44	88.44	88.44	88.44	88.44	339.08
DICKE (DEG K) :	309.60	308.62	310.05	309.29	308.34	308.28	309.49	339.08
0 VOLTS=(DEG K):	359.02	361.67	384.81	397.17	355.01	362.93	367.99	339.08
10 VOLTS=(DG K):	-43.30	-45.92	8.72	-6.73	23.82	43.69	-24.84	349.08

CALIBRATION VALUES: (VOLTS, DEGREES C)

HOT LOAD	=	3.39	66.08	DRY BULB	=	6.59	34.84
DICKE #1 (UPPER)	=	6.41	35.89	BOX INTERIOR	=	6.43	35.65
DICKE #2 (LOWER)	=	6.57	34.26	35 GHZ MIXER #1	=	6.35	36.41
35 GHZ GUNN	=	6.01	39.85	35 GHZ MIXER #2	=	10.00	0.00
95 GHZ GUNN	=	6.03	39.60	95 GHZ MIXER #1	=	10.00	0.00
95 GHZ ISOLATOR	=	6.31	36.87	95 GHZ MIXER #2	=	6.41	35.84
LARGE LENS	=	6.23	37.68	SPARE	=	10.00	0.00
WET BULB	=	10.00	0.00	SPARE	=	10.00	0.00

MIXER BIAS CURRENTS: (VOLTS, MICROAMPS)

MIXER BIAS #1	=	9.52	952.86	MIXER BIAS #3	=	7.18	1077.20
MIXER BIAS #2	=	9.49	949.20	MIXER BIAS #4	=	6.78	1017.58

THERMOCOUPLE: (VOLTS, DEGREES C)

COLD LOAD = 9.38 -184.55

Figure 8. Middle and End of Scan Calibrations.

```
CHANNEL 0 - MAX TEMP = 301.78 K, AT ROW  14 PIXEL   1 (  1.35 VOLTS)
            MIN TEMP = 146.50 K, AT ROW   8 PIXEL   8 (  4.08 VOLTS)
```


```
CHANNEL 0 - MAX TEMP = 301.78 K, AT ROW  14 PIXEL   1 (  1.35 VOLTS)
            MIN TEMP = 146.50 K, AT ROW   8 PIXEL   8 (  4.08 VOLTS)
```


0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1	299	292	292	290	286	282	277	277	280	280	282	285	289	292	292	293	295	293	290	291	295	294	295	296	294	294	297	294	292	290	6
2	293	292	289	287	286	279	274	271	270	281	284	288	295	290	292	290	291	290	289	291	295	293	294	293	296	291	288	290	285	288	6
3	294	295	292	287	282	273	270	266	262	270	269	274	287	289	290	284	283	272	277	277	285	279	286	282	283	284	284	283	279	281	0
4	296	286	283	276	263	256	255	252	256	266	260	281	286	290	284	277	270	266	267	275	272	276	276	277	274	269	271	272	270	273	10
5	291	290	270	266	240	237	232	220	224	232	245	280	264	276	283	283	271	267	263	256	256	261	260	261	259	262	255	254	262	259	17
6	279	265	252	237	216	203	[illegible]	197	202	209	232	254	264	275	284	269	260	256	247	247	243	240	245	245	240	238	240	240	262	244	24
7	280	277	264	230	213	193	177	169	180	171	194	217	238	263	270	283	270	259	243	229	232	227	230	220	223	220	229	235	240	232	33
8	275	254	217	197	177	150	153	146	157	179	190	225	259	275	281	273	262	233	226	214	207	200	204	195	202	205	219	236	255	216	39
9	291	275	260	220	209	175	162	171	173	165	196	200	234	259	279	284	275	265	241	230	217	203	204	196	203	212	211	224	265	225	30
10	280	265	241	218	201	192	190	189	195	211	227	240	272	281	280	279	270	254	241	229	222	221	213	226	227	226	240	256	283	230	31
11	294	285	271	260	244	230	231	229	230	234	239	250	260	272	289	292	287	277	266	251	250	245	245	243	244	249	252	250	282	250	20
12	294	285	270	260	250	259	259	254	257	261	260	275	282	291	294	290	287	270	273	267	265	263	257	260	267	264	266	279	293	272	12
13	295	290	290	286	281	270	279	277	270	281	281	289	287	293	293	293	293	284	285	280	276	270	274	279	276	276	281	282	289	284	6
14	301	295	295	289	291	287	289	293	289	290	294	291	299	295	294	293	292	280	290	291	284	288	287	288	284	290	287	292	295	291	4
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	296	0	0	0	0	0	0	0	0	0	0	0	0	0	0	296	0
16	291	282	271	269	247	234	232	230	233	230	240	260	273	281	280	285	279	270	264	260	257	256	255	280	285	256	259	264	276	261	0
17	7	13	22	30	37	45	47	47	44	44	35	20	19	11	6	7	12	16	21	25	29	32	32	33	32	30	27	23	15	0	33

Figure 9. Pixel Temperatures of Scan, 95 GHz Vertically Polarized. Bare metal reference about Row 8, Pixel 8. Ice target about Row 8, Pixel 24.

Monthly Progress Reports No. 3 through 7

Report Period

1 August through 31 December 1980

Report Prepared

January 6, 1981

ICE/FROST DETECTION USING MILLIMETER WAVE RADIOMETRY

J.A. Gagliano

Contract No. NAS8-33800

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Prepared for

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Prepared by

Engineering Experiment Station
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Atlanta, Georgia 30332

Work Performed During This Period

The ice measurements using External Tank (ET) target samples at Georgia Tech was completed during this period. For these measurements the ET sample target was covered with spray-on-foam-insulation (SOFI) as specified by NASA/MSFC. The SOFI sample was mounted on an aluminum subpanel which was cooled with liquid nitrogen to form ice on the SOFI surface. The ET target was scanned concurrently with an aluminum plate reference target adjacent to the ET sample. The reference target compensated for the variation in the background sky which served as the reflection source for the scanned target. Table 1 is a summary of ice detection activities at Georgia Tech.

Pixel temperature contour plots were performed using the 95 GHz radiometric data collected during the ice measurements at Georgia Tech. Figure 1 is a plot of a data run made of a dry ET target sample. The reference target is plotted to the left and the primary ET target is shown on the right. The separation distance between pixels is approximately 4.2 inches which for the 3 by 3 foot ET target sample represents an 8 by 8 pixel matrix on the contour map. For this data run, the target was located about 200 feet from the radiometer with a target viewing angle of 45°. Observe from Figure 1 that the average pixel temperature difference between the dry SOFI target (on the right) and the reference metal target (on the left) is approximately 3°K.

Following the dry ET target run, the SOFI sample was cooled inside the liquid nitrogen enclosure (previously described in Monthly Progress Report No. 1) until an approximate ice thickness of 1/8 inch was formed. An ice-covered target run was now performed at a target range of 200 feet and viewing angle of 45° as before. Figure 2 is a plot of this data run with the reference target on the left and the ET target on the right. The average pixel temperature difference between the ice covered SOFI target and the reference target is approximately 49°K which indicates that the ET target's apparent temperature increased by 46°K

Table 1

Ice Detection Activities at Georgia Tech

Activity	Comment
Scan reference target concurrent with ET target	Compensate for variation in sky background during radiometric scan
Scan dry spray-on-foam-insulation (SOFI) ET sample	Average pixel difference of 3°K between ET and reference targets
Scan ice covered SOFI ET Sample	Average pixel difference of 49°K between ET and reference targets
Printout pixel temperature contour plots of ET and reference targets	Multiple pixel temperature data per target
Display radiometric imaged scan for each data run	Imaged scan corresponds to pixel temperature printout
Vary ET sample target viewing angle for different data runs	Ice detected on target for all viewing angle runs

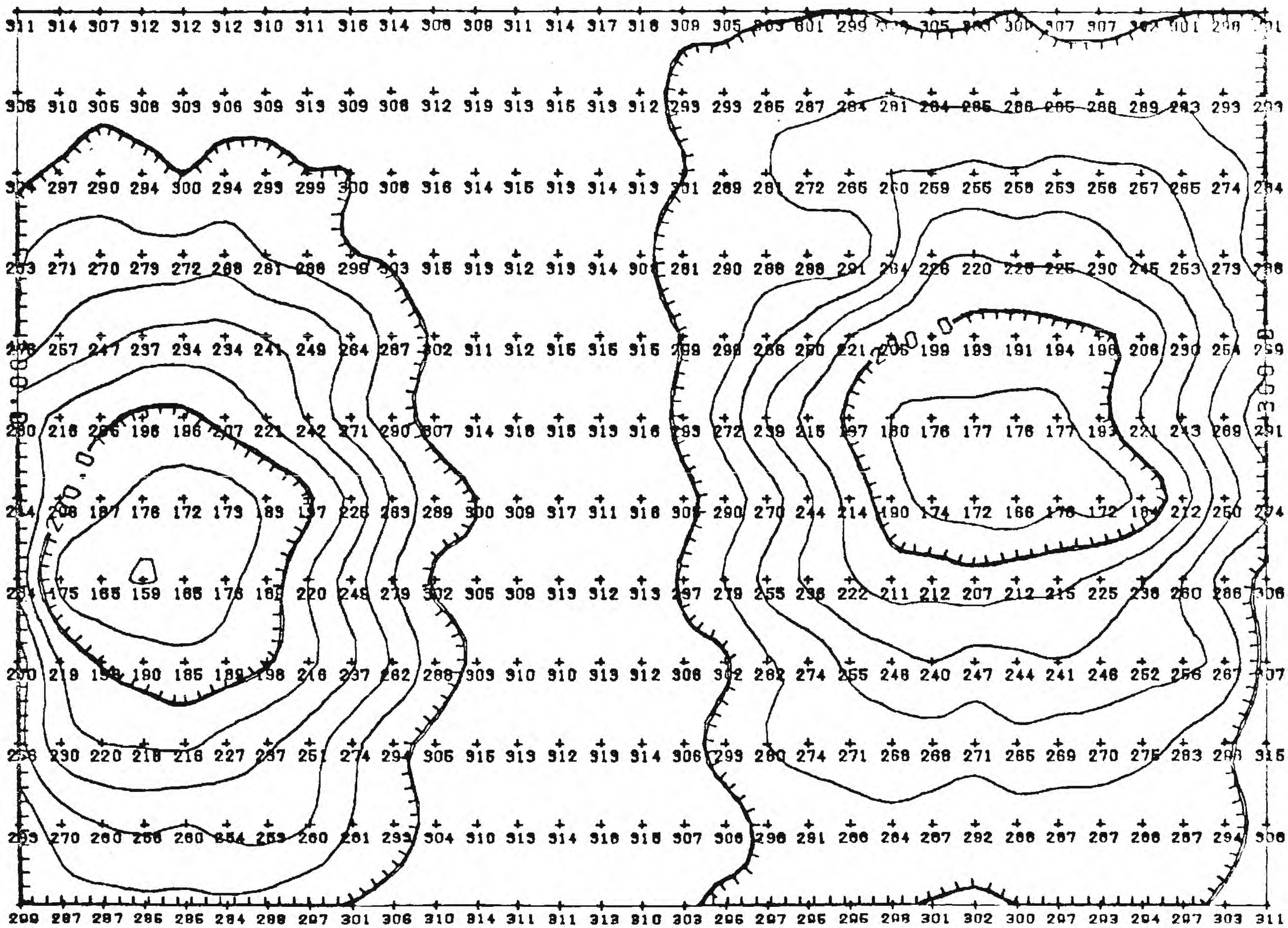

Figure 1. 95 GHz Pixel Temperature Contour Plot for Run #14, Channel #3 with Reference Target On Left and ET Target (Dry) on Right.

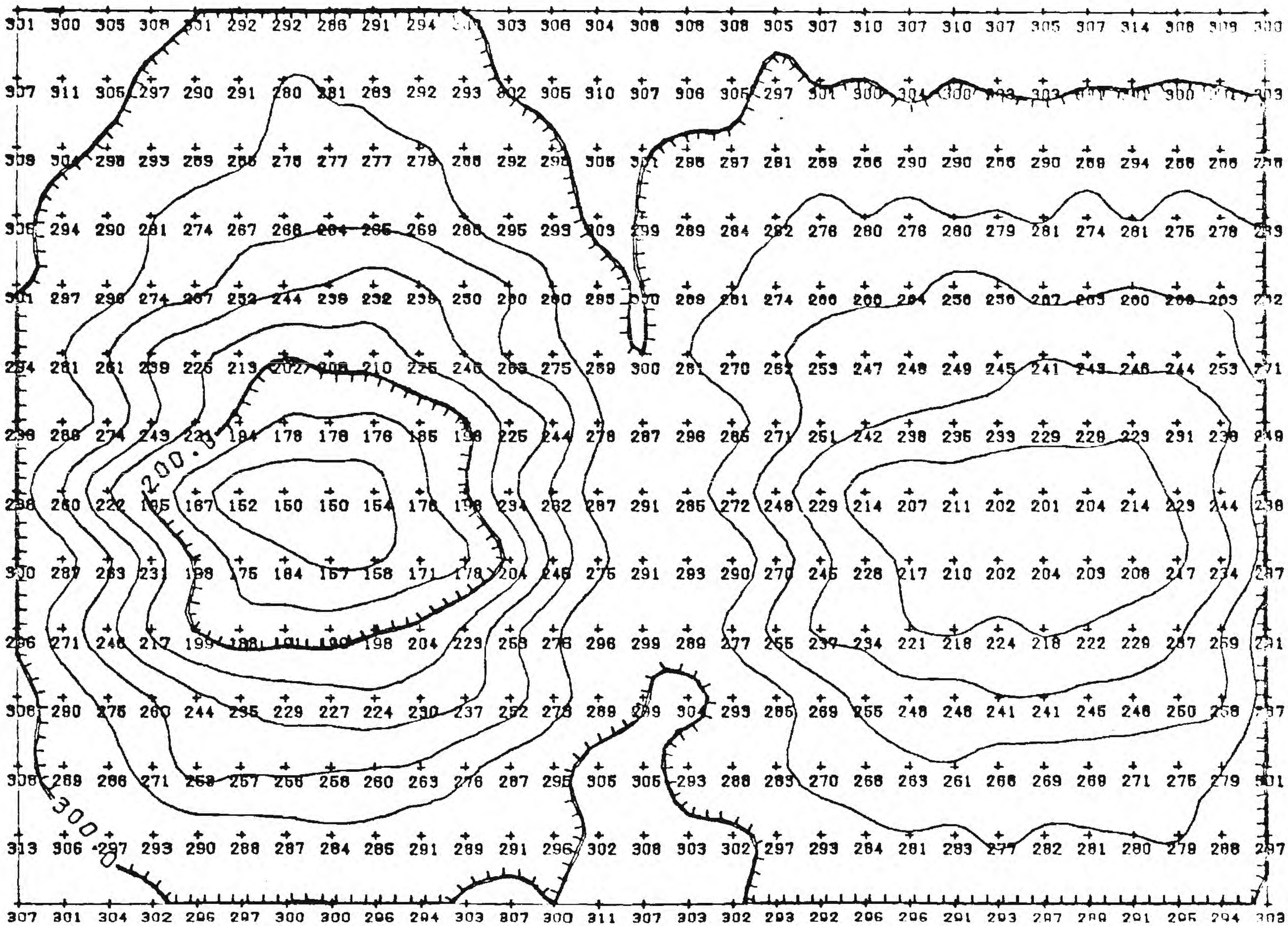

Figure 2. 95 GHz Pixel Temperature Contour Plot for Run #19, Channel #3 with Reference Target on Left and ET Target (with Ice) on Right.

when covered with ice. Table 2 summarizes the complete set of data runs performed at Georgia Tech during this phase of the ice/frost detection program.

Processing of the radiometric data taken during the ice measurements at Georgia Tech included pixel temperature contour plots, radiometric scanned images of the ice/frost signatures, and three dimensional plots of the data array. Figures 3 and 4 are data arrays plotted for the dry ET target and the ice covered ET target, respectively. For these plots the warmer radiometric temperature of the target is illustrated by the reduction in the peak of the ET target plot when ice is present.

Based on the above data using the ET target samples at Georgia Tech, the next scheduled activity during this period was an ice/frost measurement test on the shuttle external tank during actual cryogenic loading operations. Per MSFC's suggestion the site for these measurements was at the Bay St. Louis, MS facility during cryogenic loading of the ET prior to the orbiter cluster engine static firing tests. Figure 5 shows the external tank erected in the static test facility at Bay St. Louis. Thie view shows the external tank photographed from a distance of about 450 feet at the LOX dock bunker site. This was the general area at which the Georgia Tech 35/95 GHz radiometer was located during the ET scans.

For these measurements, a reference target was scanned concurrently with the ET in order to compensate for the variation in the background sky. The reference target was on the work platform nearest the upper tank section (LOX tank) as shown in Figure 5. The reference target was an aluminum sheet of 1/16 inch thickness with approximate dimensions of 4 feet by 8 feet. The reference target was tilted about 15° upward toward the sky in order to obtain an acceptable angle of sky reflection off the target.

The spatial resolution (beam spot on target) for the radiometer measurements is a function of the radiometer's antenna size, frequency of operation, and the range between the radiometer and the target.

Table 2

ET Target Sample Ice Detection Data Summary

Run#,Ch#	Sky Temp	Coldest Temperatures				Differences		Comments
		Reference	Target	$\bar{R}$ Ref. Average	$\bar{T}$ Target Avg.	T-R	$\overline{T-R}$	
20,Ø	130,128,122	167	196	179	211	29	32	Ice,1/4"FM, doors 50%cc
20,3	128,125,121	161	205	172	212	44	40	V.A. = 30°
35,Ø	73,77,78	120	125	132	136	5	4	Dry, 1/4" foam, doors 10%cc
35,3	72,72,74	89	102	108	108	13	0	V.A. = 30°
21,Ø	145,153,145	205	228	213	238	23	25	Ice, 1/4" foam, doors 90%cc
21,3	145,151,143	206	230	211	240	24	29	V.A. = 60°
36,Ø	76,75,78	183	196	206	220	13	14	Dry, 1/4" foam, doors 10%cc
36,3	72,74,76	177	192	196	206	15	10	V.A. = 60°
14,Ø	157,130,130	159	163	170	173	4	3	Dry, 1/4" foam, doors 60%cc
14,3	152,126,128	159	166	177	180	7	3	V.A. = 45°
19,Ø	128,127,130	146	195	165	210	46	45	Ice, 1/4" foam, doors 40%cc
19,3	126,127,128	150	201	162	211	51	49	V.A. = 45°
30,Ø	92,96,92	126	140	149	156	14	7	Dry, 1/4" foam, doors 5%cc
30,3	90,95,89	114	130	134	144	16	15	V.A. = 45°
33,Ø	100,106,102	119	151	143	161	32	18	Ice, 1/4" foam, doors 50%cc
33,3	97,103,99	130	155	146	168	25	22	V.A. = 45°

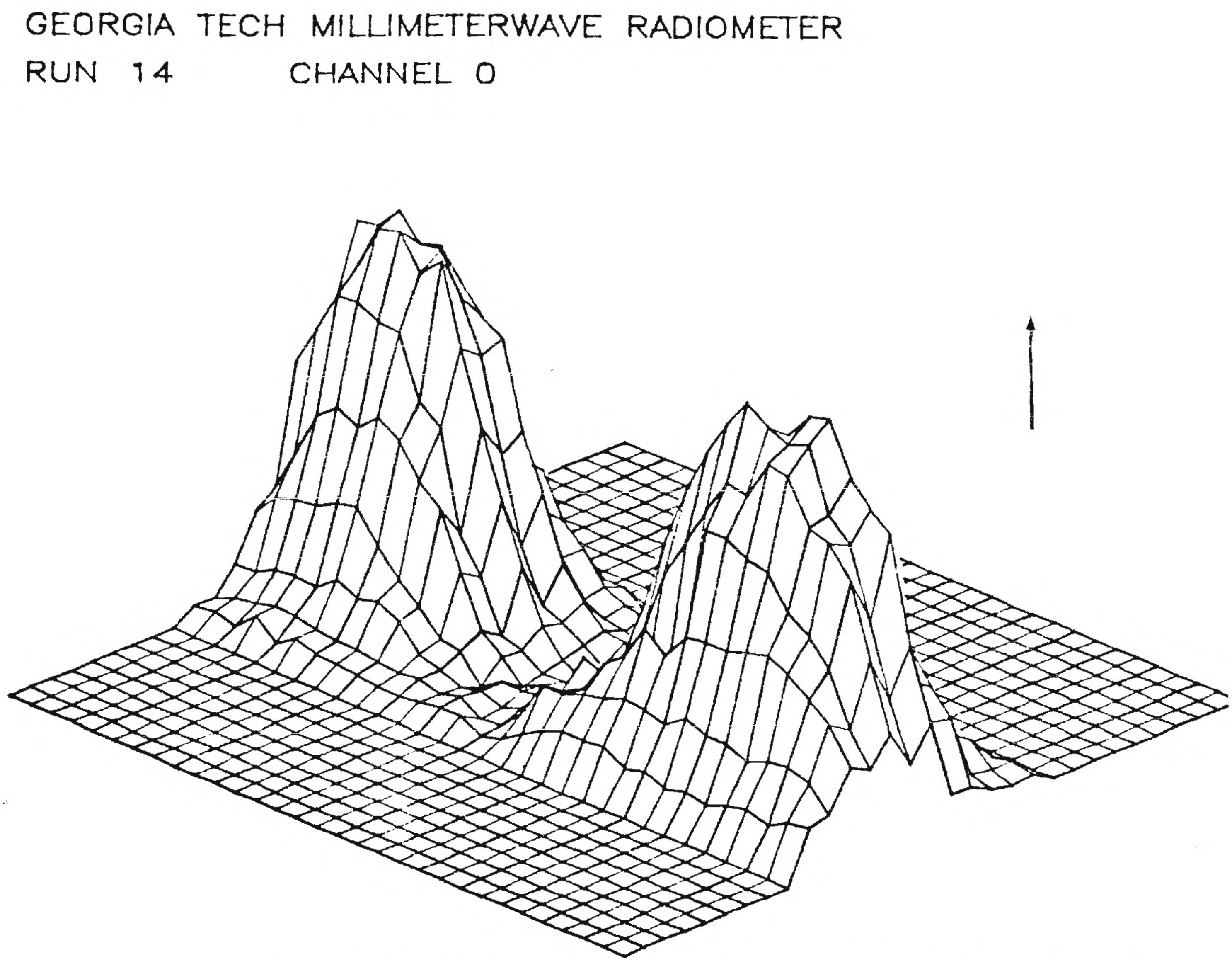

Figure 3. 95 GHz 3D Plot with Reference Target on Left and Dry ET Target on Right.

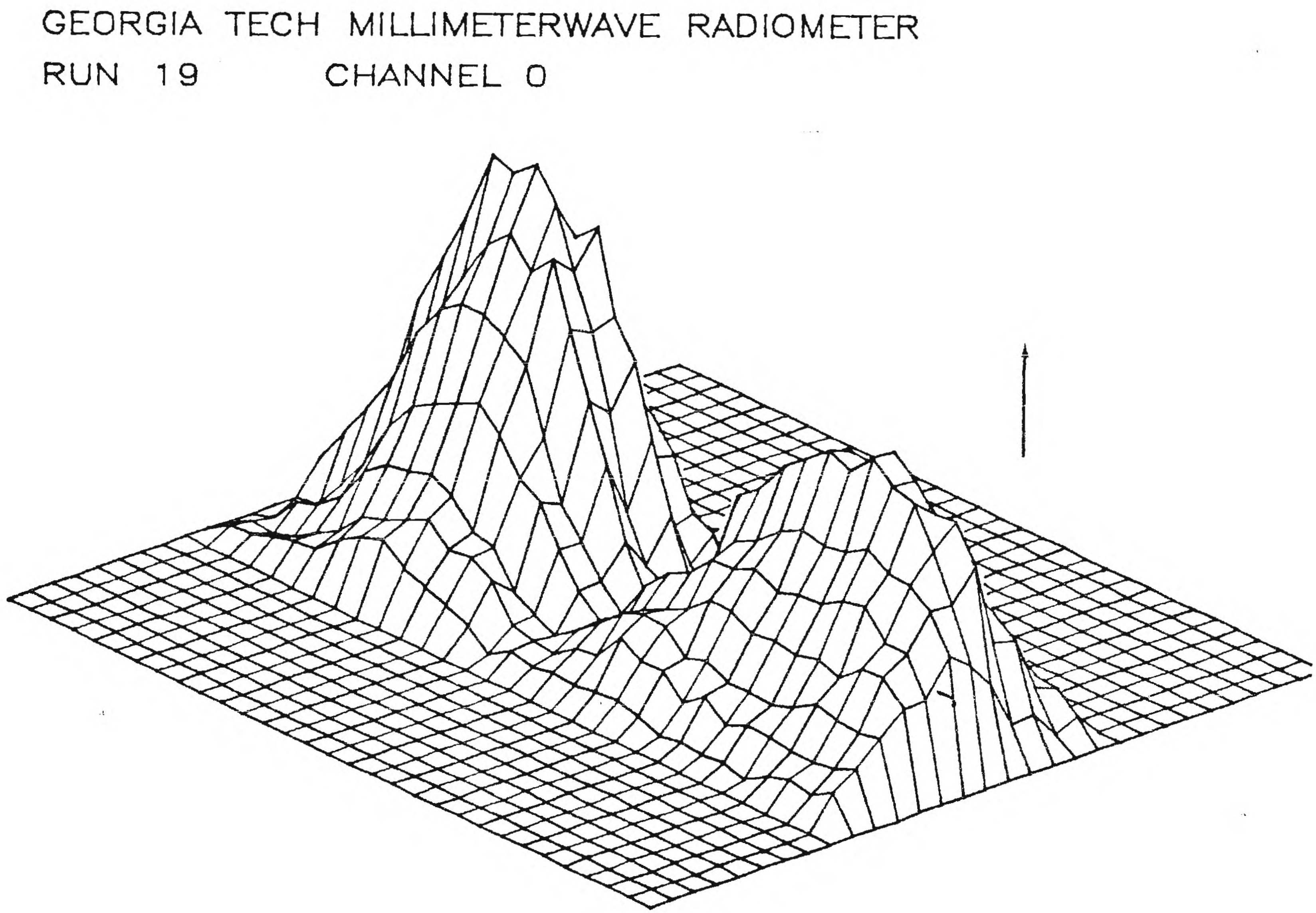

Figure 4. 95 GHz 3D Plot with Reference Target on Left and Ice Covered ET Target on Right.

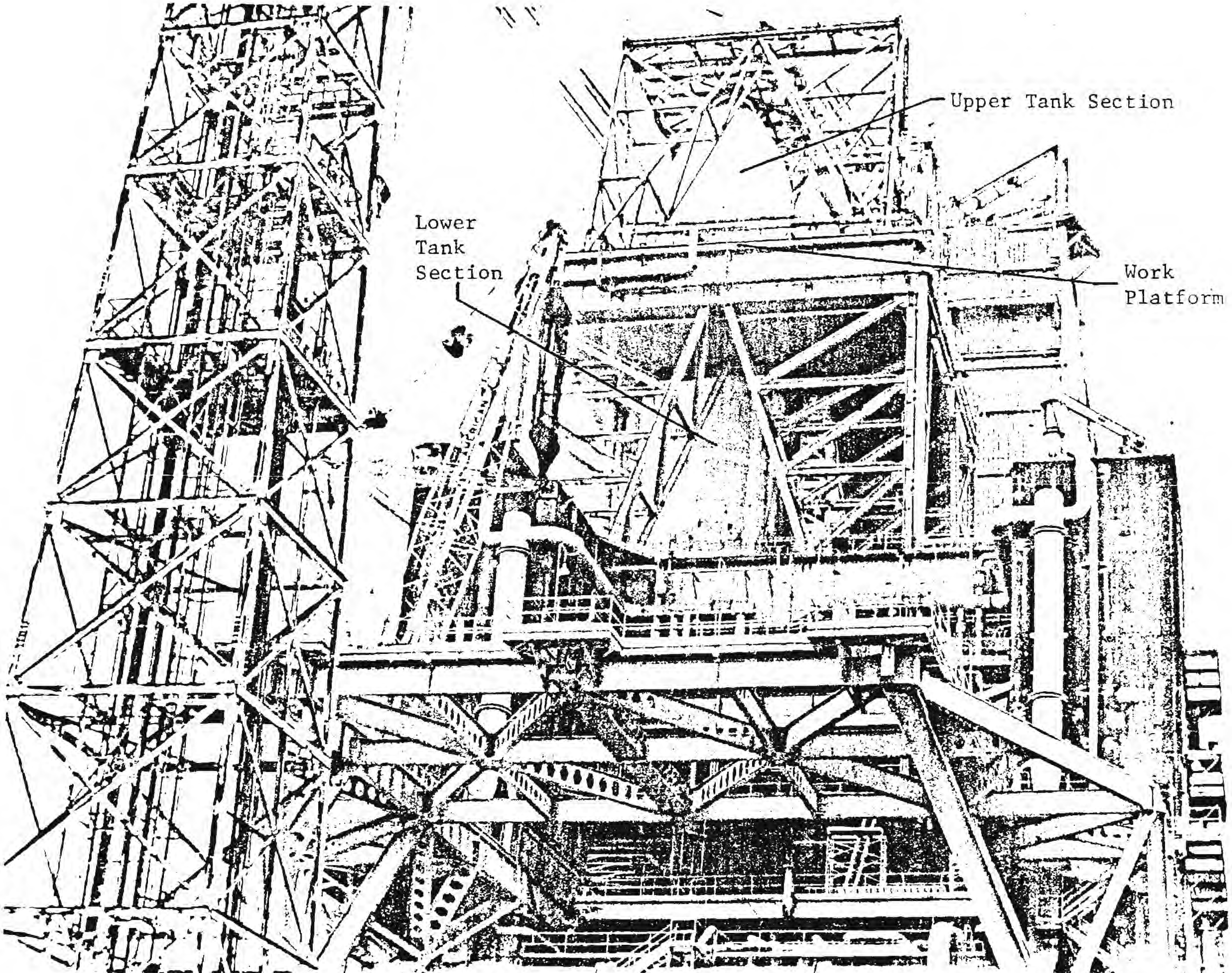

Figure 5. Shuttle External Tank on Location at Bay St. Louis Facility.

Figure 6 depicts the geometry for the ice detection measurements using the shuttle external tank as the target. The 95 GHz radiometer used for the Bay St. Louis measurements has a 20 inch diameter (D) lens which resulted in a 0.4° half power beamwidth (θ_B°) at 95 GHz. Therefore, the beam spot diameter, d, on the ET surface at a distance R from the radiometer is given by:

$$d = R\theta_B^\circ \left(\frac{\pi}{180}\right) .$$

The beam spot diameter varies as the radiometer to target range is changed according to the above equation. Table 3 summarizes the spatial resolution for the 95 GHz radiometer used for the measurements at Bay St. Louis. For a range of 450 feet the beam spot diameter was 3.14 feet. This resulted in approximately nine beamspots across the 28 foot diameter ET target at a distance of 450 feet. Table 3 also shows the number of beam spots per scan across the external tank as a function of range R.

In preparation for the field measurements, Georgia Tech improved the field readiness of the radiometer prior to shipping the system to Mississippi. These improvements included: an interconnect cable, front panel changes, and additional analog processor integrated circuits. In addition, Georgia Tech required the following support during the measurements at Bay St. Louis:

1) A forklift was needed for lifting the radiometer instrument onto the antenna positioner;
2) A supply of liquid nitrogen of about 160 liters per day was available, if needed, for the radiometer's cooled calibration loads;
3) A 4 by 8 foot aluminum plate of 1/16 inch thickness was provided to serve as the secondary reference target and was mounted near the ET LOX tank on the tower;

Table 3

95 GHz Radiometer Spatial Resolution Data For
ET Scan at Bay St. Louis

R (feet)	d (feet)	beam spots/scan cross ET
200	1.40	20.0
250	1.75	16.0
300	2.09	13.4
350	2.44	11.5
400	2.79	10.0
450	3.14	8.9
500	3.49	8.0

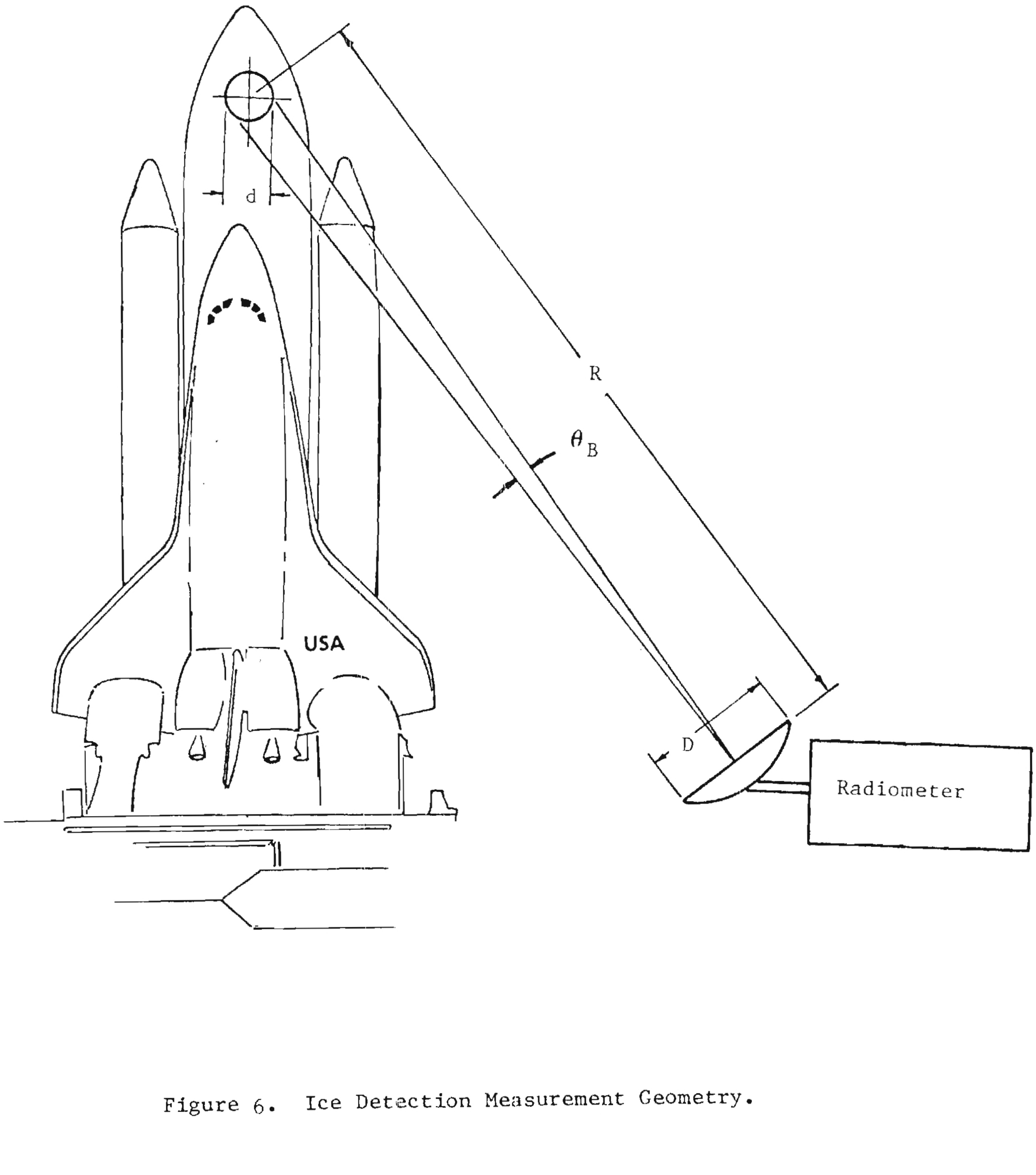

Figure 6. Ice Detection Measurement Geometry.

4) The electrical power requirements for the radiometer system of 110 Vac, 60 Hz, 50 amperes maximum was provided during the field deployment.

Problems Encountered During This Period

It was difficult to form ice on the ET sample target during measurements at Georgia Tech due to problems encountered with the cooled test enclosure. The welded aluminum reservoir containing liquid nitrogen continued to form cracks and leak so that ice could not be formed on the ET sample. As a result this method of using a reservoir for LN_2 was abandoned and, instead, water was sprayed on the SOFI target after the sample's surface temperature was reduced to near freezing. Using this method an ice thickness of 1/8 inch maximum was maintained during the radiometric scans of the target.

Work To Be Performed Next Period

A detailed analysis of the data obtained during the December 1980 cryogenic loading of the ET will be performed utilizing recently developed data processing techniques on Georgia Tech's Eclipse Computer System. These detection techniques include: the time rate of change of selected data array parameters; time and/or spatial correlations of the data; and statistical information such as mean, standard deviation, and variance calculations on selected pixel arrays from the scanned data recorded at Bay St. Louis.

At the request of MSFC, Georgia Tech will prepare a plan for additional measurements at Bay St. Louis in January 1981 in which the 35/95 GHz radiometer will be used to gather more data on the ET during cryogenic loading. This plan will recommend that the test site support personnel at Bay St. Louis provide a means of artificially forming ice on the ET while the radiometer is performing scans. This will provide a data base for evaluating the effect of ice formation on the ET. The plan will include the tasks of performing the field measurements at Bay St. Louis for approximately one week and the follow-up analysis of the data to be performed at Georgia Tech. An unofficial cost estimate on this additional scope of work will also be provided.

Cost Information

The following charges have been incurred against the contract during period 1 October through 31 December 1980.

	Expended	Encumbered
Personal Services (PS)	$10,511.85	$ -0-
Materials and Supplies	712.62	720.10
Travel	2,489.38	85.00
Overhead (@ 73% of PS)	7,673.65	-0-
Retirement (@ 11.11% of PS)	1,075.85	-0-
TOTAL	$22,463.35	$ 805.10

The breakdown of personal services is as follows:

	Dollars	Approximate Man Hours
Principal Research Scientists/Engineers	$ -0-	-0-
Senior Research Scientists/Engineers	-0-	-0-
Research Scientists II/Engineers II	1,457.88	95
Research Scientists I/Engineers I	8,000.35	651
Technicians/Draftsmen	-0-	-0-
Students	828.10	148
Secretarial/Clerical/Other	225.52	34
TOTAL	$10,511.85	928

The current financial status of the contract is as follows:

	Budget As Proposed	Expended	Free Balance
Personal Services (PS)	$41,216.00	$30,199.32	$11,016.68
Materials and Supplies	5,255.00	4,698.78	(363.88)
Travel and Shipping	4,060.00	2,603.19	1,371.81
Computer	500.00	-0-	500.00
Overhead	30,610.00	22,133.57	8,476.43
Retirement	4,474.00	2,721.91	1,752.09
Encumbered	-0-	1,555.10	-0-
FUNDING	$86,115.00	$63,911.87	$22,203.13

Based on present full funding, the funding and equivalent man hours are sufficient to complete the task. Approximately 74 % of the proposed task has been completed.

11-0660

Monthly Progress Report No. 8

Report Period

1 January through 31 January 1981

Report Prepared

18 January 1981

ICE/FROST DETECTION USING MILLIMETER WAVE RADIOMETRY

J.A. Gagliano

Contract No. NAS8-33800

Project No. A-2668

Prepared for

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Prepared by

Engineering Experiment Station
Georgia Institute of Technology
Atlanta, Georgia 30332

Work Performed During This Period

Georgia Tech provided field personnel at NSTL during the January 1981 Orbiter engine firings tests in order to perform ET ice formation measurements using the 35/95 GHz instrumentation radiometer. These measurements were requested by NASA to obtain additional ice signature data by artificially forming ice on the ET after the completion of cryogenic loading. Figure 1 is a view of the LOX section of the ET which was the target area viewed by the radiometer during the tests. This site was chosen because it provided the best radiometric view of the LOX tank and it was the prime location of the support facilities at NSTL.

Georgia Tech requested that NASA provide a cut-out section of 1 meter square on the LOX tank prior to the loading of cryogenics. The thickness of the SOFI was reduced to 1/2 inch in the cut-out area. Figure 2 is a close-up view of this area where ice was formed by Georgia Tech personnel after the cryogenic loading operation. This cut-out section was included in the ET target area scanned throughout the entire test sequence. Radiometric imaging of the ET LOX section is shown in Figure 3 which shows eight hours of continuous scanned data on the tank. This scan sequence contains sixteen consecutive images, each of 30 minutes duration. The total sequence shown includes: 1 hour of data prior to ET loading, 5.5 hours of data taken with the tank partially or fully loaded, and 1.5 hours of data collected immediately after engine firing.

Table 1 provides a description of each 30 minute scan beginning with the ET pre-loading and ending with the post-engine firing. During scan 10, ice was artificially formed on the cut-out section after the ET was fully loaded with cryogenics. Data measurements with the Georgia Tech radiometer revealed an increase of approximately 20°K in the apparent temperature of the ET cut-out area on the LOX tank. This is indicative of the reduction in the cold sky reflection off the ET surface due to the presence of ice. This same effect was observed

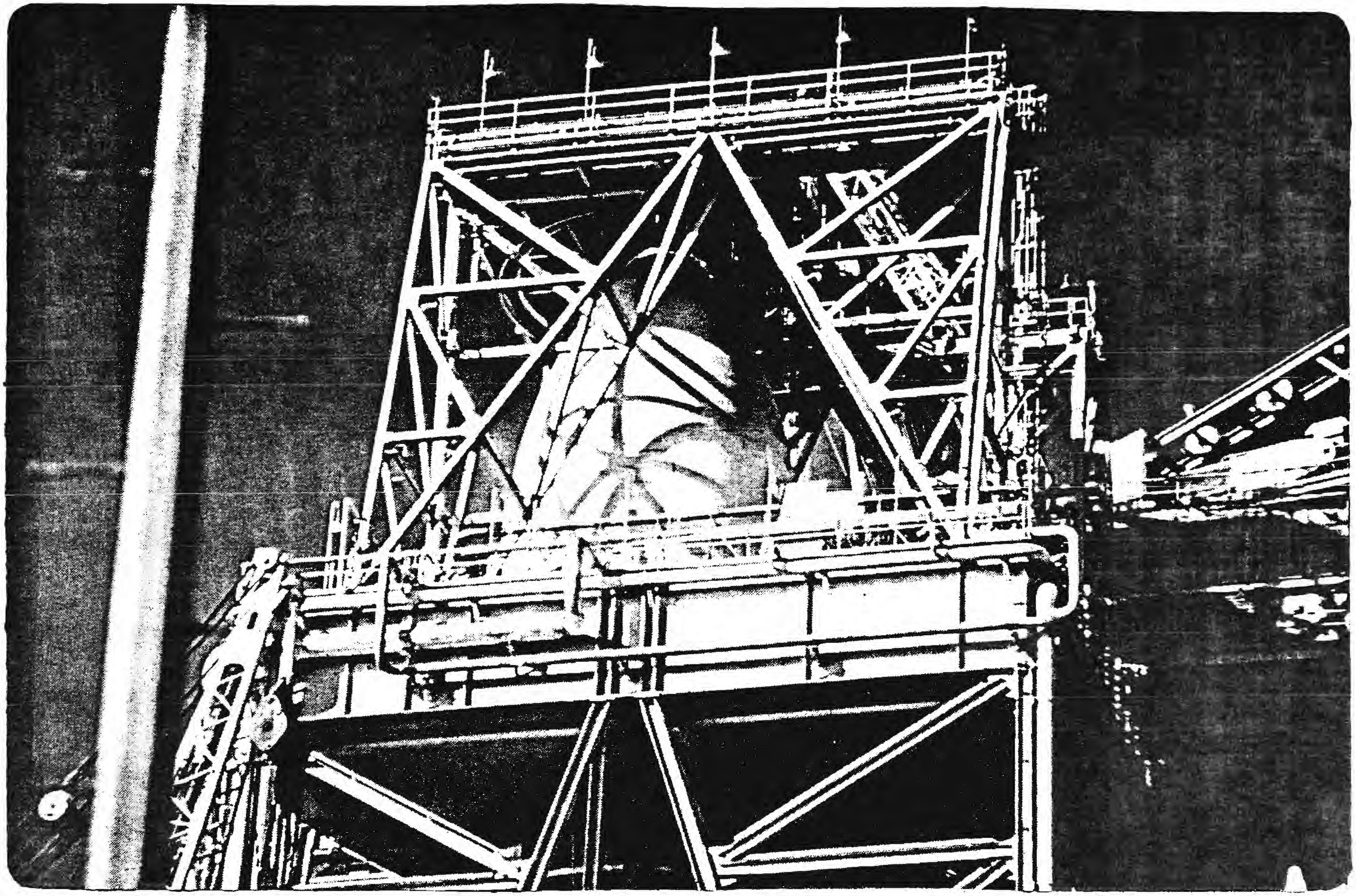

Figure 1. View of Shuttle ET LOX Tank as Seen by Georgia Tech Instrumentation Radiometer.

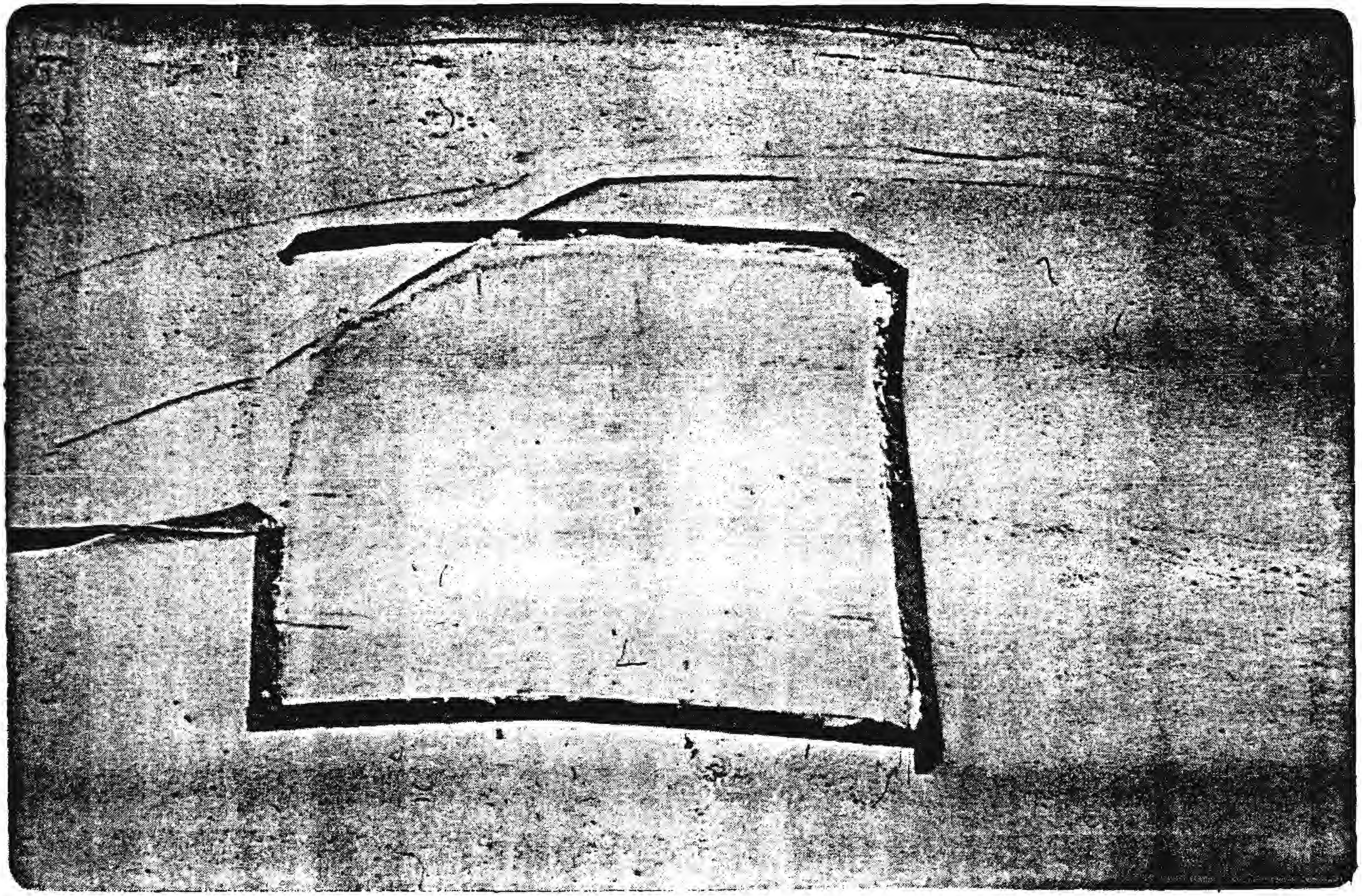

Figure 2. Close-up View of 1 Meter Square Cut-out Section Located on ET LOX Tank.

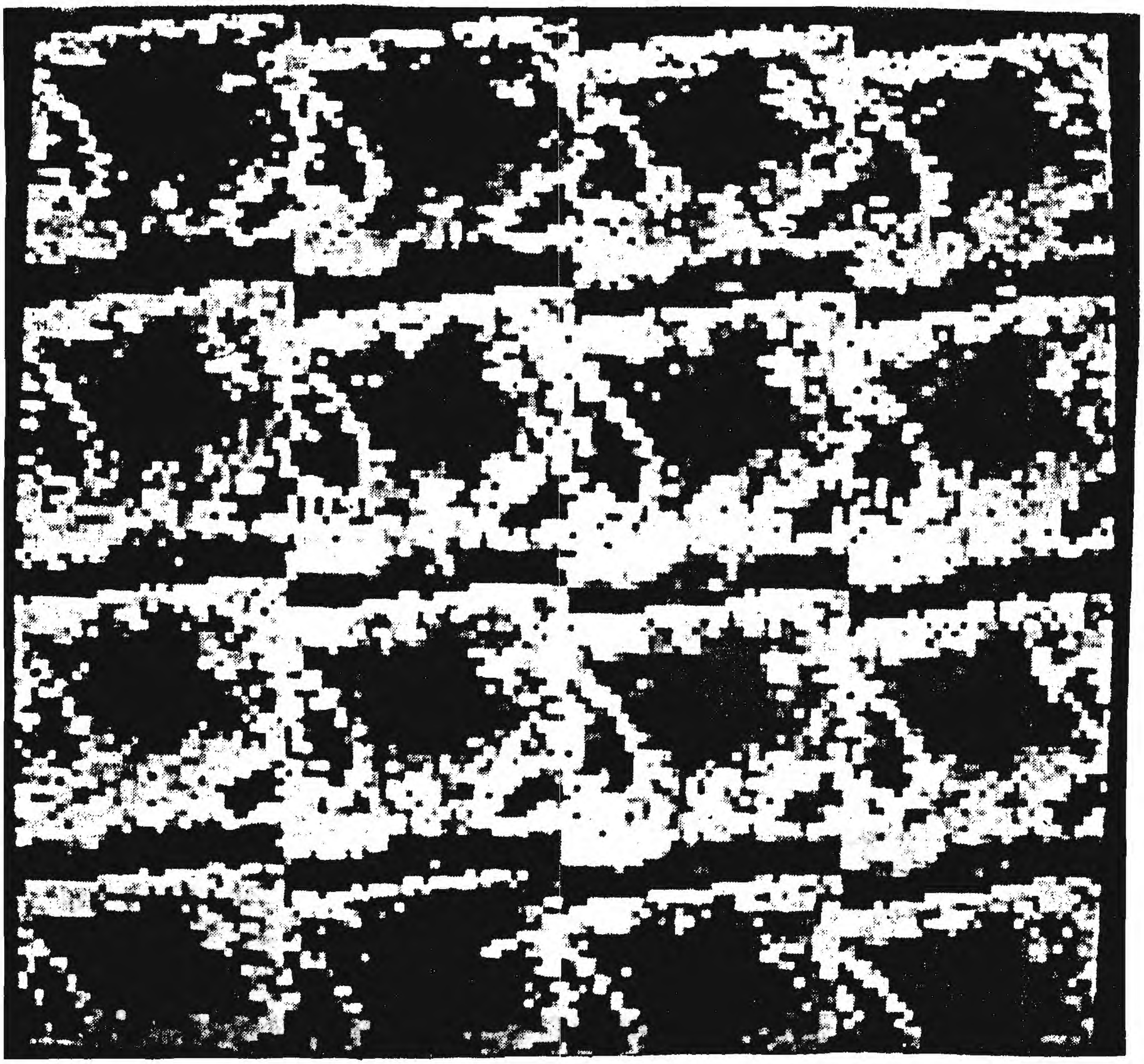

Figure 3. 95 GHz Imaging Scan Sequence of Shuttle ET at NSTL.

Table 1

95 GHz RADIOMETRIC IMAGING SCAN SEQUENCE FOR ET DURING CRYOGENIC LOADING PROCEDURES

Scan(s) Note 1	Description
1&2	ET Pre-loading Scans
3&4	ET Loading Scans
5-8	ET Loading/Post-Loading Scans
9	ET Post-Loading Scan
10	Ice Formed on Cut-out
11&12	Ice on Cut-out
13	Engine Firing During Scan
14-16	ET Scans After Engine Firing

Note 1. Scan sequence as follows (see Figure 3).

1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16

during the measurements performed in August 1980 at Georgia Tech on ET target samples which were covered with spray-on-foam-insulation (SOFI).

Following the January 1981 ice measurements at NSTL, Georgia Tech personnel presented the data results to NASA representatives at MSFC. In addition a proposed plan for additional measurements with improved spatial resolution using the Georgia Tech 35/95 GHz radiometer was presented. The plan involves the addition of a 4-foot dish to the radiometer in order to reduce the beam spot diameter on target by approximately 2.4. NASA agreed that a new set of measurements at NSTL or KSC with the improved spatial resolution are necessary to gather additional data on the ET target. Georgia Tech agreed to provide a detailed plan to NASA next month regarding the recommended improvements to the radiometer required before the measurements are performed.

Problems Encountered During This Period

No problems to report at this time.

Work To Be Performed Next Period

Georgia Tech will prepare the proposed work efforts to continue the shuttle ET ice detection program for MSFC. The tasks to be proposed for future work include: new improved spatial resolution measurements on the shuttle ET, detailed data analysis of NSTL ice signature data gathered during the December 1980 and January 1981 tests, and a prototype 95 GHz scanning radiometer design for a system to be used at KSC during the shuttle ET cryogenic loading procedures.

Cost Information

The following charges have been incurred against the contract during period 1 January through 31 January 1981.

	Expended	Encumbered
Personal Services (PS)	$ 8,920.11	$ -0-
Materials and Supplies	1,343.26	458.10
Travel	1,179.83	1,115.00
Overhead (@ 73% of PS)	6,511.68	-0-
Retirement (@ 11.11% of PS)	936.14	-0-
Capital Outlay	551.66	(550.00)
TOTAL	$19,442.68	$1,023.10

The breakdown of personal services is as follows:

	Dollars	Approximate Man Hours
Principal Research Scientists/Engineers	$ -0-	-0-
Senior Research Scientists/Engineers	1,893.90	98
Research Scientists II/Engineers II	728.94	47
Research Scientists I/Engineers I	5,577.81	454
Technicians/Draftsmen	-0-	-0-
Students	486.30	87
Secretarial/Clerical/Other	233.16	35
TOTAL	$8,920.11	721

The current financial status of the contract is as follows:

	Budget As Proposed	Expended	Free Balance
Personal Services (PS)	$41,216.00	$39,119.43	$2,096.57
Materials and Supplies	5,255.00	7,420.24	(2,165.24)
Travel and Shipping	4,060.00	4,983.02	(923.02)
Computer	500.00	-0-	500.00
Overhead	30,610.00	28,645.25	1,964.75
Retirement	4,474.00	3,658.05	815.95
Capital Outlay	-0-	551.66	(551.66)
Encumbered	-0-	2,578.20	-0-
FUNDING	$86,115.00	$84,377.65	$1,737.35

Based on present full funding, the funding and equivalent man hours are sufficient to complete the task. Approximately 98% of the proposed task has been completed.

Monthly Progress Report No. 9

Report Period

1 February through 28 February 1981

Report Prepared

March 31, 1981

ICE/FROST DETECTION USING MILLIMETER WAVE RADIOMETRY

J.A. Gagliano

Contract No. NAS8-33800

Project No. A-2668

Prepared for

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Prepared by

Engineering Experiment Station
Georgia Institute of Technology
Atlanta, Georgia 30332

Work Performed During This Period

Proposed efforts for continued work on the Shuttle ET Ice Detection Program, Contract No. NAS8-33800, were submitted to the sponsor during this period. Tasks submitted included: an improvement in the system's spatial resolution with the addition of a 4-foot dish to the 35/95 GHz instrumentation radiometer; follow-up measurement program on the Shuttle ET at Kennedy Space Center (KSC); detailed data analysis, using advanced techniques, of the NSTL ice signature collected during the December 1980 and January 1981 test firings; and, the system design of a prototype 95 GHz scanning radiometer for use at KSC during the Shuttle ET cryogenic loading procedures.

At the direction of MSFC, the 4-foot dish needed to improve the system's spatial resolution was ordered from Milliflect Microwave Antenna Specialists with a delivery date estimate of mid-March 1981. Figure 1 illustrates how the 35/95 GHz instrumentation radiometer will be modified in order to provide a resolution cell of 23 inches at a range of 600 feet. Plans call for preparing the radiometer for measurements at KSC on either external tank ET-1 (April 1981) or ET-2 (June/July 1981) to determine the target geometry for later use in the design of a prototype instrument.

The proposed task to develop new algorithms to analyze the previously collected NSTL ice signature data was submitted to MSFC for review. This data analysis task, if performed, would support the evidence to date that millimeter wave radiometry provides a viable means to detect ice formation on the ET. Techniques submitted for NASA's review include:

1) pixel temperature contour plots;
2) three dimensional plots;
3) statistical information such as mean, standard deviation, variance, and correlation coefficient calculations based on selected pixel arrays from the scanned data;
4) time rate of change of selected data array parameters,
5) time and/or spatial correlations of the data;

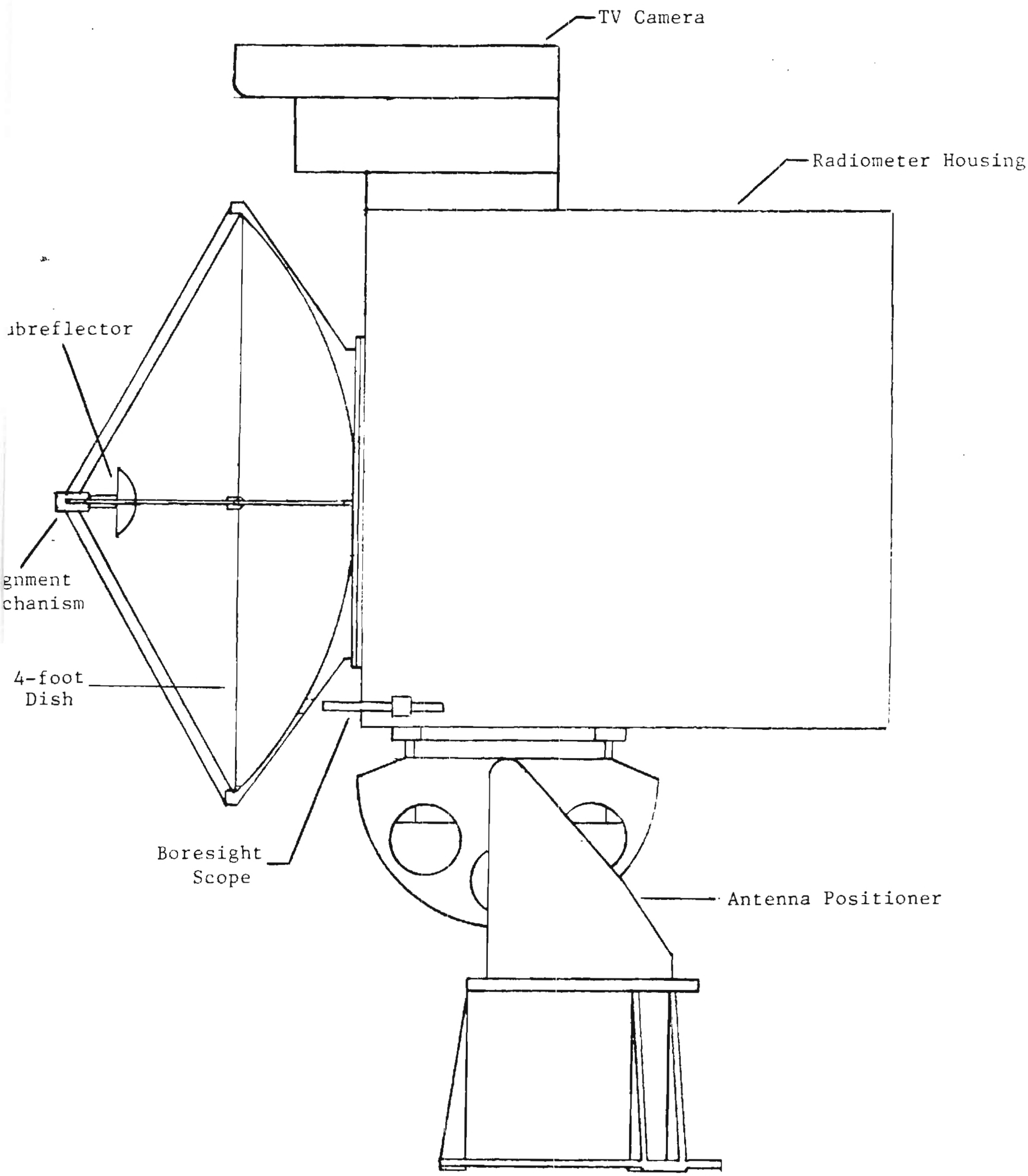

Figure 1. Georgia Tech 35/95 GHz Radiometer Modified for Improved Spatial Resolution.

6) data sampling corrections to compensate for arcs formed by current sampling pattern;

7) Fast Fourier Transform (FFT) analysis;

8) polarization comparisons;

9) data deconvolutions by inverse linear filtering.

Problems Encountered During This Period

Modifications to the 35/95 GHz radiometer for improved resolution are pending the arrival of the 4-foot dish from Milliflect. Final system tests of the radiometer with the new dish antenna requires the installation of an elevation tachometer in the antenna positioner for serve control feedback. A field engineer from Scientific Atlanta will be scheduled to perform the installation at Georgia Tech.

Work To Be Performed During the Next Period

Plans call for completing the integration of the 4-foot dish antenna with the 35/95 GHz radiometer for future ice formation measurements on the Shuttle ET. Following the direction of the MSFC technical monitor, the next phase of the ice detection program will be to perform advanced data analysis techniques on the NSTL ice signature data from previous tests. Those techniques selected will be discussed with NASA/MSFC to determine which algorithms should be developed before the next ice measurements are performed.

Cost Information

The following charges have been incurred against the contract during period 1 February through 28 February 1981.

	Expended	Encumbered
Personal Services (PS)	$ 8,401.14	$ -0-
Materials and Supplies	1,157.22	1,828.60
Travel	666.86	(1,200.00)
Overhead (@ 73% of PS)	6,132.83	-0-
Retirement (@ 11.11% of PS)	808.31	-0-
TOTAL	$17,166.36	$ 628.60

The breakdown of personal services is as follows:

	Dollars	Approximate Man Hours
Principal Research Scientists/Engineers	-0-	-0-
Senior Research Scientists/Engineers	$1,893.90	98
Research Scientists II/Engineers II	2.041.03	133
Research Scientists I/Engineers I	3,115.19	253
Technicians/Draftsmen	-0-	-0-
Students	1,125.50	201
Secretarial/Clerical/Other	225.52	34
TOTAL	$8,401.14	719

The current financial status of the contract is as follows:

	Budget As Proposed	Expended	Free Balance
Personal Services (PS)	$41,216.00	$ 47,520.57	$(6,304.57)
Materials and Supplies	5,255.00	7,199.26	(5,151.06
Travel and Shipping	4,060.00	4,449.88	(389.88)
Computer	500.00	-0-	500.00
Overhead	30,610.00	34,778.08	(4,168.08)
Retirement	4,474.00	4,466.36	7.64
Encumbered	-0-	3,206.80	-0-
Funding	$86,115.00 + 42,866.00* $128,981.00	$102,172.61	$(16,057.61) + 42,866.00* $26,808.39

Based on present full funding, the funding and equivalent man hours are sufficient to complete the task. Approximately 79% of the proposed task has been completed.

* New funding increment effective 3-17-81.

Monthly Progress Report No. 10

Report Period

1 March through 31 March 1981

Report Prepared

April 15, 1981

ICE/FROST DETECTION USING MILLIMETER WAVE RADIOMETRY

J.A. Gagliano

Contract No. NAS8-33800

Project No. A-2668

Prepared for

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Prepared by

Engineering Experiment Station
Georgia Institute of Technology
Atlanta, Georgia 30332

Work Performed During this Period

Integration of the 4-foot dish with subreflector and the 35/95 GHz radiometer was completed. Fabrication of the 6 inch lens for mounting at the base of the dish was begun. An analysis of the total torques due to wind and weight loading as a function of wind speed was performed on the radiometer's antenna positioner. Table 1 provides a summary of the torque analysis compared to the specifications on the antenna positioner per the vendor (Scientific Atlanta). According to this table no problems would occur under normal wind conditions at KSC.

Problems Encountered During This Period

Final system tests of the radiometer with the 4-foot dish are delayed due to the 6 inch lens still in fabrication.

Work to be Performed Next Period

Work will continue on the software to provide statistical information on the NSTL ice signature data, such as mean, standard deviation, and variance on selected pixel arrays.

Table 1

Total Torque Calculation Summary for the Radiometer's Antenna Positioner Using 4-foot Dish

Positioner Axis	Specification	Total Torque for Wind Speed of 40 MPH	60 MPH	80 MPH
Elevation	800 ft-lb	269	486	819*
Azimuth	600 ft-lb	55	115	203

*80 MPH wind speed would exceed launch conditions

Cost Information

The following charges have been incurred against the contract during period March 1 through 31 March 1981

	Expended	Encumbered
Personal Services (PS)	$ 8,357.11	-0-
Materials and Supplies	2,142.39	(1,769.80)
Travel	-0-	-0-
Overhead (@ 73% of PS)	6,100.69	-0-
Retirement (@ 11.11% of PS)	803.84	-0-
TOTAL	$17,404.03	$(1,769.80)

The breakdown of personal services is as follows:

	Dollars	Approximate Man Hours
Principal Research Scientists/Engineers	$ 125.99	5
Senior Research Scientists/Engineers	948.73	49
Research Scientists II/Engineers II	1,749.45	114
Research Scientists I/Engineers I	3,429.60	279
Technicians/Draftsmen	752.23	85
Students	1,121.70	201
Secretarial/Clerical/Other	229.41	35
TOTAL	$8,357.11	768

The current financial status of the contract is as follows:

	Budget As Proposed	Expended	Free Balance
Personal Services (PS)	$41,216.00	$ 56,060.83	$(14,844.83)
Materials and Supplies	5,255.00	9,341.65	(5,523.65)
Travel and Shipping	4,060.00	4,449.88	(389.88)
Computer	500.00	-0-	500.00
Overhead	30,610.00	41,012.47	(10,402.47)
Retirement	4,474.00	5,290.55	(816.55)
Encumbered	-0-	1,437.00	-0-
Capital Outlay	-0-	551.66	(551.66)
	$86,115.00	$118,144.04	$(32,029.04)
FUNDING	+ 42,866.00*		+ 42,866.00*
	$128,981.00		$ 10,836.96

Based on present full funding, the funding and equivalent man hours are sufficient to complete the task. Approximately 92 % of the proposed task has been completed.

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*New funding increment effective 3-17-81.

H-2668

Monthly Progress Report No. 10

Report Period

April 1 through April 30, 1981

Report Prepared

May 7, 1981

ICE/FROST DETECTION USING MILLIMETER WAVE RADIOMETRY

J.A. Gagliano

Contract No. NAS8-33800

Project No. A-2668

Prepared for

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Prepared by

Engineering Experiment Station
Georgia Institute of Technology
Atlanta, Georgia 30332

Work Performed During This Period

System tests were performed on the 35/95 GHz radiometer with the 4-foot dish antenna installed. Figure 1 is a photograph of the radiometer showing the dish antenna mounted to the front-end. Antenna pattern measurements yielded a 3 dB beamwidth, $\theta°$, of 0.22° at 95 GHz. For use at the shuttle launch facility at KSC, the radiometer's spatial resolution at 95 GHz is given by:

$$d = R\theta°(\frac{\pi}{180})$$

where d = beam spot diameter

R = distance from ET to radiometer

θ = half power beamwidth in degrees.

This spatial resolution yields an improvement (reduction) in the target beam spot area by a factor of approximately four from the previous tests performed at NSTL. Table 1 summarizes the beam spot diameter (d) and area (A_T) as a function of target range (R), for the 95 GHz portion of the radiometer.

The data analysis routine for the mean, standard deviation, and the variance of the NSTL ice signature data was developed during this period. Emphasis was placed on that data gathered during the January 1981 NSTL tests in which ice was artificially formed on a section of the LOX tank between the cryogenic loading and the engine firing sequence. Figure 2 provides a view of the ET LOX section as seen by the radiometer on location at NSTL. Locations of interest within the radiometer's scan pattern are provided in Table 2. Section 11 is the actual cut-out area in which approximately a 1 square meter section of the ET had its foam thickness reduced to 1/2 inch. This cut-out area is contained within the larger area designated as 9.

Table 3 illustrates the results of the ice signature analysis routine showing pertinent statistical information. Data run #149 was the last 30 minute scan performed prior to the artificial formation of ice. Data run #150 was the next scan which included the presence of ice. Observe the increase in radiometric mean temperature of

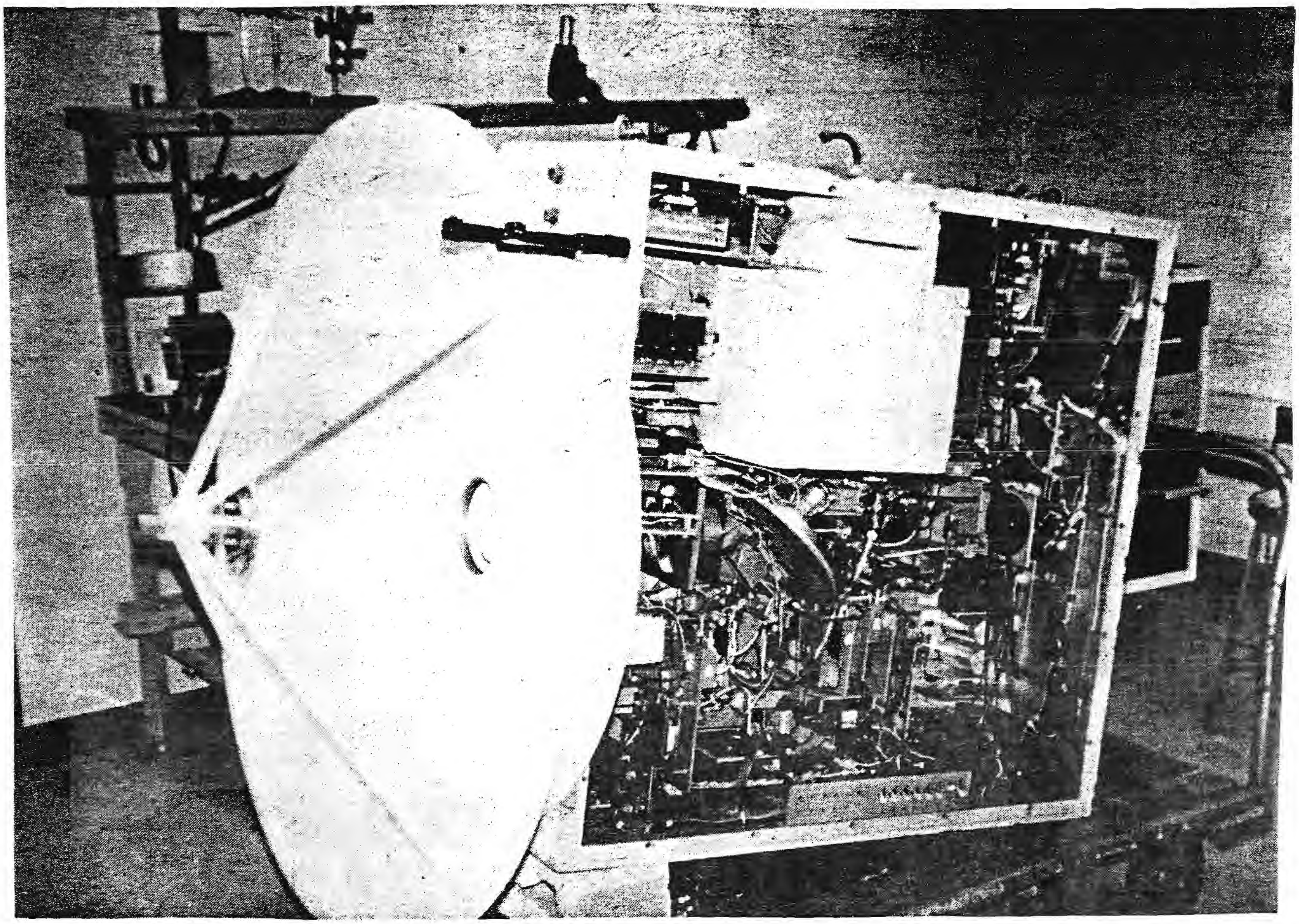

Figure 1. Georgia Tech 35/95 GHz Radiometer Showing 4-foot Dish Antenna and Electronics.

Table 1

95 GHz Radiometer Spatial Resolution Data Using 4-Foot Antenna Dish (Note 1)

R(ft)	d(ft)	$A_T(ft^2)$
450	1.728	2.345
500	1.920	2.895
550	2.112	3.503
600	2.304	4.169

Note 1. $d = R\theta°(\frac{\pi}{180})$, for $\theta° = 0.22$ degrees and $A_T = \frac{\pi d^2}{4}$.

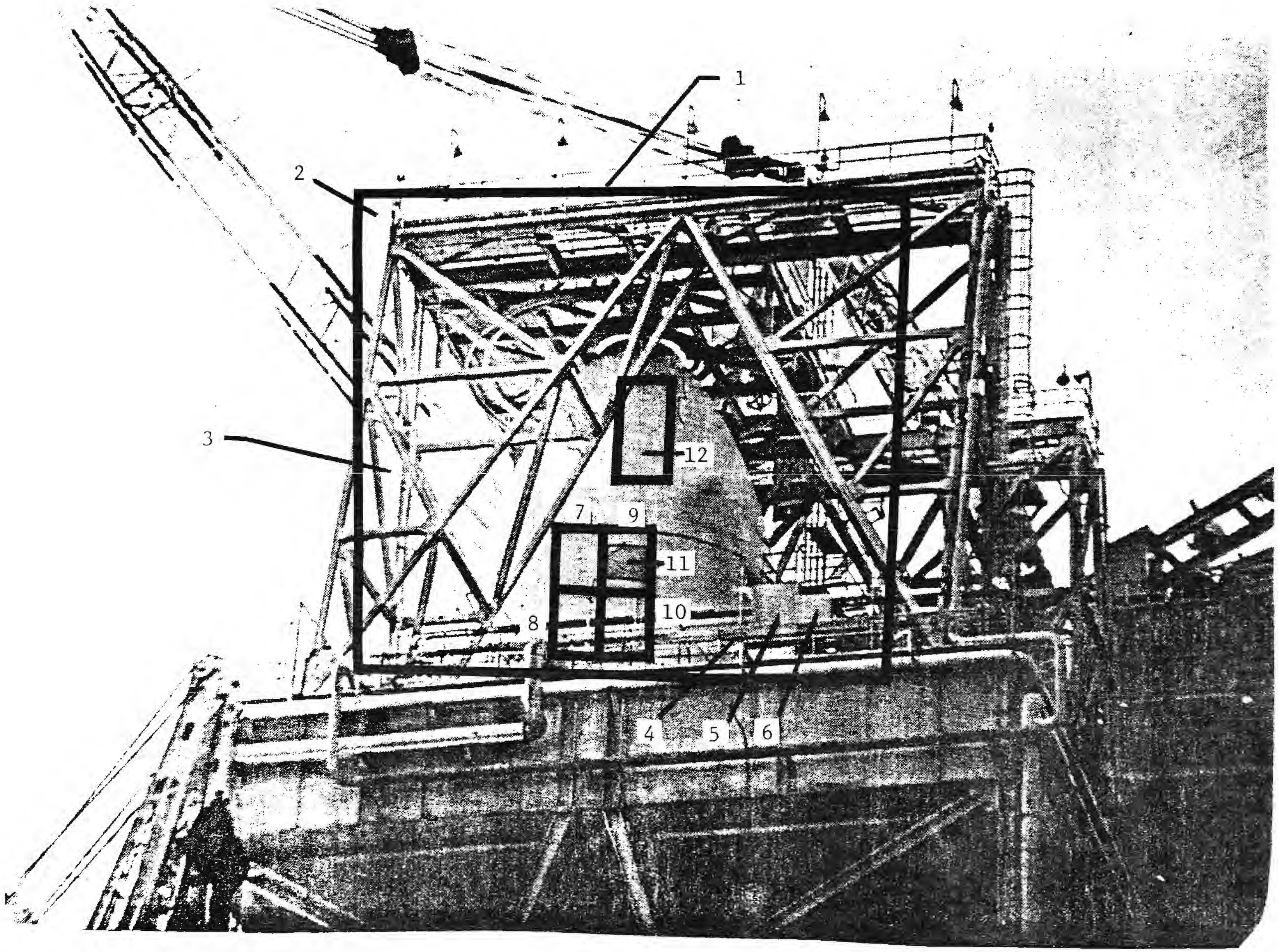

Figure 2. View of ET LOX Section at NSTL as Seen by 35/95 GHz Scanning Radiometer. (Refer to Table 2 for section call out.)

Table 2

Specified Areas Within the Radiometer's Scan of the NSTL ET LOX

Section(s)	Description
1	33 pixel by 33 row scan of LOX tank and surroundings
2	Sky view with minimum structure blockage
3	Sky view with partial structure blockage
4	Rail structure on stand beneath reference targets
5	Metal reference target
6	SOFI reference target
7,8	Sections adjacent to foam cut-out region
9	Section containing SOFI cut-out area
10	Area beneath cut-out region
11	SOFI cut-out (foam reduced to 1/2 inch thickness)
12	Upper portion of LOX tank

Table 3

NSTL Data Runs (Scans) #149 and #150 from 95 GHz
Vertical Polarization Radiometric Data Output

SECTION	TL COORDS	LR COORDS	NPTS	MEAN	VARIANCE	STD DEV
1	0, 0	32, 31	1056	145.2	839.3	28.97
2	0, 0	5, 2	18	74.3	321.1	17.92
3	1, 18	4, 21	16	104.9	221.1	14.87
4	21, 29	33, 32	52	187.5	260.8	16.15
5	25, 22	27, 26	15	98.2	251.2	15.85
6	28, 23	29, 26	8	104.4	464.3	21.55
7	12, 20	14, 24	15	149.0	37.5	6.13
8	12, 25	14, 29	15	152.1	128.9	11.35
9	15, 20	17, 24	15	130.4	155.7	12.48
10	15, 25	17, 29	15	146.0	388.3	19.70
11	15, 22	17, 23	6	124.1	123.8	11.13
12	15, 10	18, 15	24	186.3	26.0	5.10

a) RUN 149 CHANNEL 0
TH= 333.10 TC= 80.51 TSKY= 29.21 TLEN= 276.25
SCENE SIZE IS 33 PIXELS BY 33 ROWS
MIN AND MAX TEMPS ARE : 47, 212

SECTION	TL COORDS	LR COORDS	NPTS	MEAN	VARIANCE	STD DEV
1	0, 0	32, 31	1056	147.6	811.0	28.48
2	0, 0	5, 2	18	71.7	150.2	12.25
3	1, 18	4, 21	16	108.0	216.1	14.70
4	21, 29	33, 32	52	187.5	184.1	13.57
5	25, 22	27, 26	15	101.2	354.1	18.82
6	28, 23	29, 26	8	111.2	173.0	13.15
7	12, 20	14, 24	15	148.8	79.1	8.89
8	12, 25	14, 29	15	156.6	87.5	9.36
9	15, 20	17, 24	15	148.3	36.0	6.00
10	15, 25	17, 29	15	154.4	98.2	9.91
11	15, 22	17, 23	6	144.0	8.3	2.88
12	15, 10	18, 15	24	186.0	42.6	6.53

b) RUN 150 CHANNEL 0
TH= 333.12 TC= 80.51 TSKY= 29.63 TLEN= 277.49
SCENE SIZE IS 33 PIXELS BY 33 ROWS
MIN AND MAX TEMPS ARE : 42, 205

TH = hot calibrate load (°K)
TSKY = sky temperature (°K)
MIN and MAX Temps = minimum and maximum temp. (°K) for run
NPTS = number of sample points in section
TC = cold calibrate load (°K)
TLEN = antenna lens (°K)
TL COORDS, LR COORDS = top-left and lower right coordinates for each section
MEAN = section mean temp. (°K)
VARIANCE, STD DEV = variance and standard deviation (°K) for section

approximately 20K from run #149 to #150 on the sections (9 and 11) containing the cut-out foam region. Visual inspection revealed ice present on the cut-out section which resulted in an apparent warming in radiometric temperature. This was expected due to the reduction in sky reflection off the foam surface caused by the ice formation.

Problems Encountered During This Period

No problems to report at this time.

Work to be Performed During the Next Period

Work will continue on data processing and analysis of ice signature data. The proposed test plan for the next phase KSC measurements with improved spatial resolution will be prepared.

Cost Information

The following charges have been incurred against the contract during period April 1 through April 30, 1981

	Expended	Encumbered
Personal Services (PS)	$3,776.39	-0-
Materials and Supplies	596.06	(237.00)
Travel	-0-	-0-
Overhead (@ 73% of PS)	2,756.75	-0-
Retirement (@ 11.11% of PS)	543.73	-0-
TOTAL	$7,472.93	(237.00)

The breakdown of personal services is as follows:

	Dollars	Approximate Man Hours
Principal Research Scientists/Engineers	-0-	-0-
Senior Research Scientists/Engineers	$ 335.27	17
Research Scientists II/Engineers II	583.15	40
Research Scientists I/Engineers I	1,767.10	144
Technicians/Draftsmen	137.67	16
Students	682.55	122
Secretarial/Clerical/Other	270.65	41
TOTAL	$3,776.39	380

The current financial status of the contract is as follows:

	Budget As Proposed	Expended	Free Balance
Personal Services (PS)	$ 60,442.00	$ 59,837.22	$ 604.78
Materials and Supplies	9,194.00	9,937.71	(743.71)
Travel and Shipping	7,590.00	4,449.88	3,140.12
Computer	500.00	-0-	500.00
Overhead	44,645.00	43,769.22	875.78
Retirement	6,610.00	5,634.28	975.72
Encumbered	-0-	1,200.00	(1,200.00)
Capital Outlay	-0-	551.66	(551.66)
FUNDING	$128,981.00	$125,379.97	$3,601.03

Based on present full funding, the funding and equivalent man hours are sufficient to complete the task. Approximately 97% of the proposed task has been completed.

A-2668

FINAL TECHNICAL REPORT

PROJECT NO. A–2668

ICE/FROST DETECTION USING MILLIMETER WAVE RADIOMETRY

By

J. A. Gagliano, J. M. Newton, A. R. Davis, and M. L. Foster

Final Report for Period 28 May 1980 – 31 August 1981

Prepared For

NASA George C. Marshall Space Flight Center
MSFC, Alabama 35812

Under

NASA Contract NAS8-33800

31 August 1981

GEORGIA INSTITUTE OF TECHNOLOGY

A Unit of the University System of Georgia
Engineering Experiment Station
Atlanta, Georgia 30332

1981

Final Technical Report
Project A-2668

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16. Abstract

A series of ice detection tests were performed on the shuttle external tank (ET) and on ET target samples using the Georgia Tech 35/95GHz instrumentation radiometer. The ET target sample tests were performed at Georgia Tech using a test enclosure containing ET Spray-On-Foam-Insulation (SOFI) samples. Ice was formed using liquid nitrogen and water spray inside the Georgia Tech designed test enclosure. The shuttle ET tests were performed at NASA's National Space Technology Laboratory (NSTL) during cryogenic fueling operations prior to the shuttle orbiter engine firing tests. Ice was formed with freon and water over a one meter square section of the ET LOX tank. Data analysis was performed on the ice signatures, collected by the radiometer, using Georgia Tech computing facilities. Data analysis techniques developed during this program include: ice signature images of scanned ET target; pixel temperature contour plots; time correlation of target data with ice present versus no ice formation; and ice signature radiometric temperature statistical data, i.e. mean, variance, and standard deviation.

17. Key Words (Selected by Author(s))	18. Distribution Statement
95GHz, Multichannel scanning radiometer, Data Collection Processor, Ice signature analysis	

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Unclassified	Unclassified	55	

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1.0 Introduction

In accordance with Contract No. NAS8-33800 for NASA/MSFC, Georgia Tech has investigated the use of an advanced instrumentation radiometer operating at 35/95 GHz to detect the presence of ice on the space shuttle external tank (ET). Other methods used in the past to detect ice formation have included infrared (IR) sensors, TV camera display, visual observations, and thermocouples. The need for remote operation a distance from the launch site eliminates visual observation just prior to launch. A TV display has not demonstrated accuracy in verifying the presence of ice from a remote location several hundred feet from the external tank. Thermocouples measure the actual temperature of the ET surface so that frost, ice and cold, clear areas would not be distinguishable. In addition, a large number of thermocouples would be needed to cover the entire ET target for ice detection. Finally, sensing devices operating in the millimeter wave spectrum can penetrate rain, fog, or dust with more effectiveness than IR sensors due to the lower propagation loss at millimeter wave lengths.

Table 1 is a summary of activities performed by Georgia Tech during the period of this contract. These activities were performed with the purpose of demonstrating that millimeter wave radiometry techniques could be used to detect ice formation on target samples at Georgia Tech and on the ET following cryogenic loading operations at NASA's shuttle test facility in Mississippi.

Samples of the shuttle external tank (ET) Spray-On-Foam-Insulation (SOFI) target were utilized during the measurements performed at Georgia Tech. This activity formed the basis of the measurement task performed by Georgia Tech to evaluate the ice/frost signature under varying conditions for weather, target viewing angle and distance. Table 2 summarizes the major activities associated with Phase 1a measurements.

Upon evaluation by NASA of the ice signature data collected at Georgia Tech, a request was made to perform additional measurements at the NASA National Space Technology Laboratory (NSTL) near Bay St. Louis,

Table 1

Ice Detection Program Summary

Phase	Activity	Status
1a	Performed ice/frost detection measurements on external tank (ET) samples under varying environment conditions using the existing Georgia Tech millimeter wave radiometer operating at 95 GHz.	Contract No. NAS8-33800
1b	Used existing Georgia Tech instrumentation radiometer to perform additional ice/frost measurements on shuttle ET during actual cryogenic loading procedures at National Space Technology Laboratory (NSTL) in Mississippi.	NAS8-33800 Contract Mod. #2
1c	Modified existing Georgia Tech 35/95 GHz radiometer for improved spatial resolution with the addition of a 4-foot dish and further analysis of ice signature data gathered at NSTL.	NAS8-33800 Contract Mods #3 & #4

Table 2

Ice Detection Activities at Georgia Tech (Phase 1a)

Activity	Comment
Scan reference target concurrent with ET target	Compensate for variation in sky background during radiometric scan
Scan dry spray-on-foam-insulation (SOFI) ET sample	Average pixel difference of 3°K between ET and reference targets
Scan ice covered SOFI ET Sample	Average pixel difference of 49°K between ET and reference targets
Printout pixel temperature contour plots of ET and reference targets	Multiple pixel temperature data per target
Display radiometric imaged scan for each data run	Imaged scan corresponds to pixel temperature printout
Vary ET sample target viewing angle for different data runs	Ice detected on target for all viewing angle runs

Mississippi where the shuttle external tank was undergoing cryogenic loading procedures. This task offered a good opportunity for Georgia Tech to obtain ice signature data on the ET during cryogenic loading operations in order to detect ice formation. For the measurements at Georgia Tech, a significant effort was put into the formation of ice on the target using a Georgia Tech designed test enclosure. The measurements at NSTL allowed for complete dedication to the task of detecting ice on the ET and for processing the data in real time using the Georgia Tech Data Collection Processor (DCP). Table 3 summarizes the activities performed at NSTL.

Following the measurements at NSTL, NASA requested that Georgia Tech improve the spatial resolution of the radiometer in preparation for proposed future tests on the shuttle ET at Kennedy Space Center (KSC). For this task Georgia Tech replaced the 20 inch lens antenna with a 4 foot dish which reduced the beam spot diameter to approximately 1.7 feet at a distance of 450 feet from radiometer to target. Antenna pattern measurements, performed at Georgia Tech, yielded a 3 dB beamwidth of 0.22° at 95 GHz.

A continuing task throughout the ice detection program was the data analysis effort performed by Georgia Tech on the data collected during the measurements. The analysis techniques were performed using the radiometer's DCP, Georgia Tech's Eclipse computer system, and the on-campus Cyber computer facility. Data processing techniques included: near real-time imaging of the scanned target; hard copy printouts of data run header information and calibration data; pixel temperature contour plotting; ice signature radiometric temperature statistical data, i.e., mean, variance, and standard deviation; and time correlation of target data with and without ice formation.

The ice detection program performed by Georgia Tech has led to a viable means to detect the formation of ice on the ET surface using a millimeter wave scanning radiometer. It has been demonstrated that a dedicated sensor could be built and located near the space shuttle launch facility in the future. Figure 1 depicts the operational

Table 3

Shuttle ET Ice Detection Activities at NSTL (Phase 1b)
Performed in December 1980 and January 1981

Activity	Comment
Scan reference targets (2) concurrent with ET	Compensate for sky background variation using bare metal and SOFI reference targets
Integrate elevation tachnometer into instrumentation radiometer	Maintain constant scan speed for varying torque with elevation angle near 25 degrees
Eight hours of continuous radiometric scans of ET with scan repeated every 30 minutes	ET scanning continuous from pre-loading of cryogenic to post-firing of orbiter engines
Scan ET cut-out section of 1 meter square having reduced foam thickness	Ice was formed on cut-out region following loading and was detected by 95 GHz radiometer
Generate on-line radiometric images of scanned ET after tank is loaded	Average brightness temperature increase of about 20K observed on cut-out section with ice present

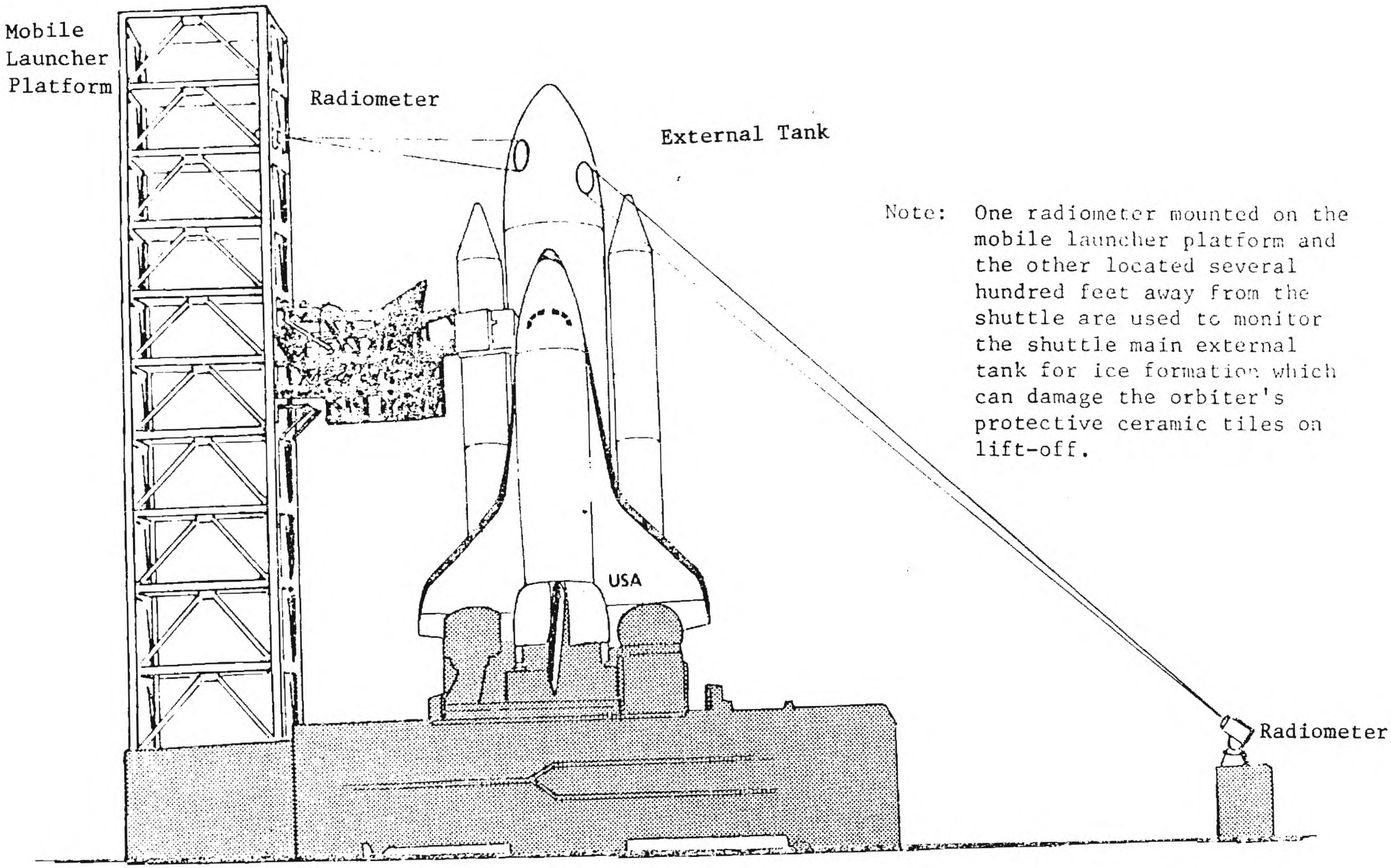


Figure 1. Shuttle Launch Facility Showing Ice Detection Radiometer Systems.

configuration of two millimeter wave sensors located at the shuttle launch facility which would provide ET surface monitoring from remote sites. The data analysis algorithms developed by Georgia Tech have demonstrated that on-line processing of ice signature could be performed prior to a shuttle launch operation. The results of the data processing could be used to aid in NASA's decision as to a go or no-go launch of the shuttle due to the accumulation of ice on the external tank.

2.0 Technical Discussion

2.1 Radiometric Measurement Techniques

The measurements at Georgia Tech and NSTL were performed using the 35/95 GHz instrumentation scanning radiometer developed by Georgia Tech. Figure 2 is a photograph of the Georgia Tech radiometer used for all ice detection measurements performed during this program. For the measurements performed at Georgia Tech the target scanned was an ET sample with SOFI. Figure 3 is a photograph of the target chamber designed by Georgia Tech for these measurements. An aluminum plate of 1/2 inch thickness located inside the chamber served as a liquid nitrogen reservoir for reducing the target temperature to below freezing. The target sample of dimensions 3 feet by 3 feet by 1/4 inch SOFI thickness was mounted to this aluminum plate. Horizontal pivot bearings on each side of the target chamber allowed for a variation in the target deflection angle over a nominal range of 30° to 60°.

The measurements at NSTL were performed on a shuttle external tank (ET) undergoing cryogenic loading prior to orbiter engine firing operations. Figure 4 is a view of the ET as seen from the radiometer located about 450 feet away. This is the general area from which the Georgia Tech 35/95 GHz radiometer scanned the ET during cryogenic loading operations. The spatial resolution (beam spot diameter on target) for the radiometer is a function of the sensor's antenna size, operating frequency, and distance from the target to the radiometer. Figure 5 depicts the geometry for the ice detection measurements using the ET as the target scanned. For these measurements, the 95 GHz radiometer had a 0.4° half power beamwidth (θ_B°) using a 20 inch diameter (D) lens. The beam spot diameter (d) on target at a range R from the radiometer is given by:

$$d = R\theta_B^\circ \frac{\pi}{180} \quad .$$

The beam spot diameter varied with the radiometer to target range, R, according to the above equation. For the NSTL measurements at 95 GHz and a range of 450 feet, the beam spot diameter on target is given by:

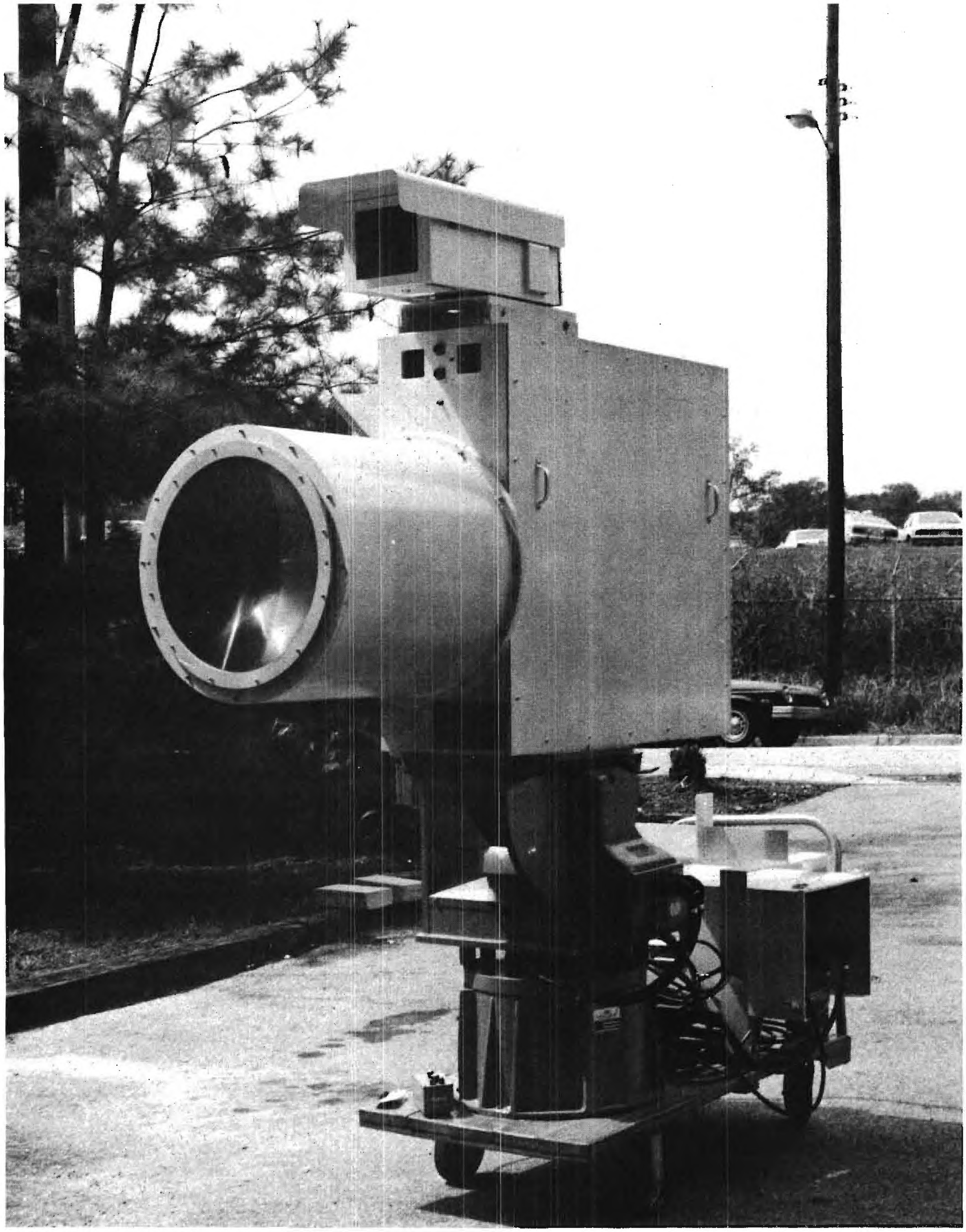


Figure 2. Radiometer Assembly - Front View.

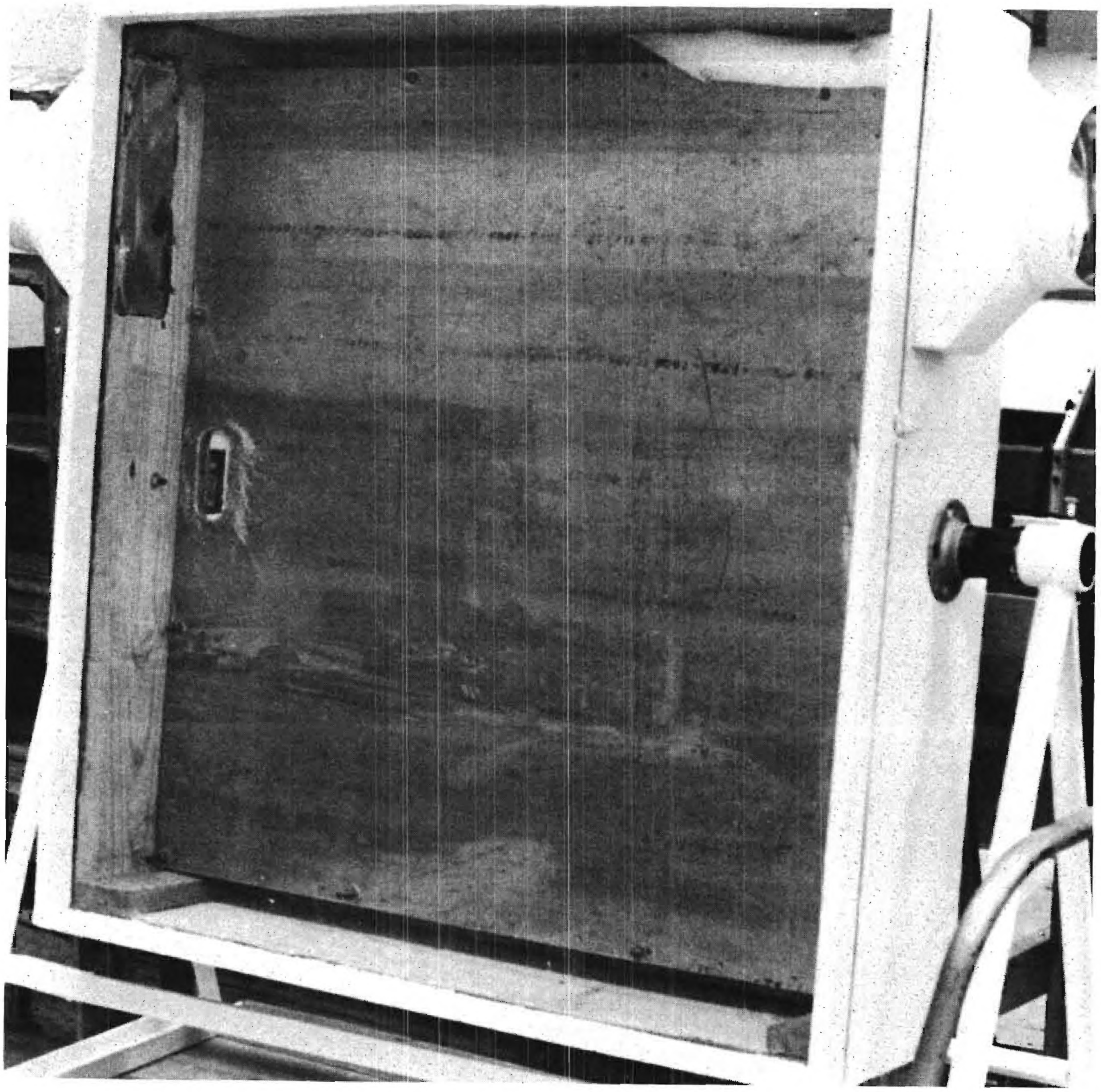


Figure 3. Ice/Frost Detector Test Enclosure for External Tank Target Samples.

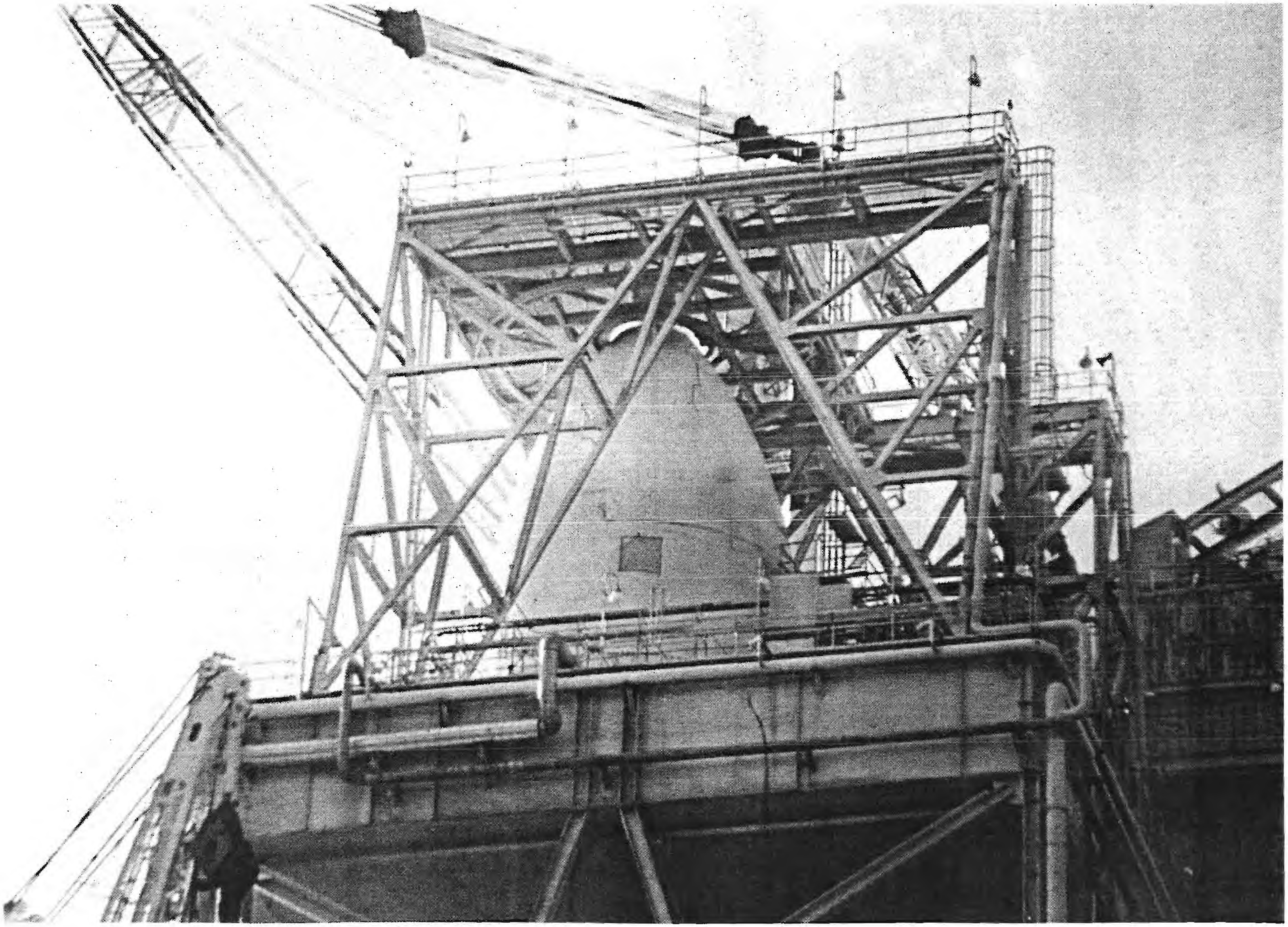


Figure 4. View of External Tank at NSTL Facility as Seen from Georgia Tech Radiometer.

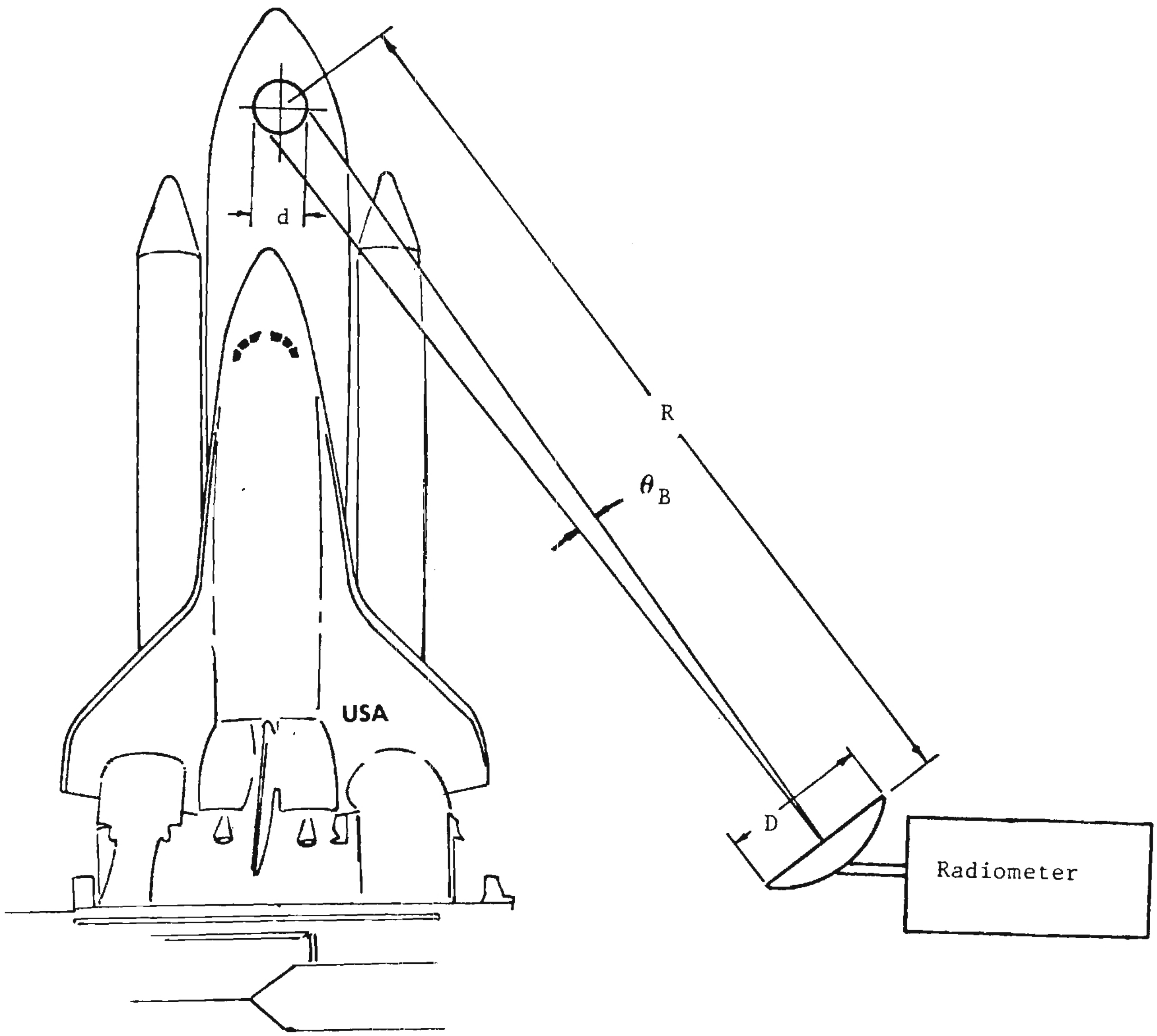


Figure 5. Ice Detection Measurement Geometry.

$$d = (450)(0.4)\,\frac{\pi}{180}$$

$$= 3.14 \text{ feet.}$$

Since the ET diameter is approximately 28 feet, then the number of beam spots across the target was 28/3.14 = 8.9 beam spots per scan across the ET diameter.

2.2 Radiometer Hardware Description

Figure 6 is a detailed block diagram of the scanning millimeter wave radiometer used for performing ice/frost signature measurements. The radiometer and associated instrumentation consists of the following elements: internal hot/cold load calibration system, 35 GHz RF head (scene and sky viewing), 95 GHz RF head (scene and sky viewing), TV camera unit (scene truth), a rotary platform for the sensors, radiometer receiver (IF amplifiers, filters, square law detectors, synchonous detectors, and integrators), microcomputer based data acquisition system, and a reel-reel tape recorder. A pictorial diagram of the system is shown in Figure 7. The measurement radiometer provides precise scene resolution, low noise operation for good temperature resolution, adequate stabilization of electronics for good temperature resolution, and good absolute temperature measurement accuracy.

The radiometer performs dual frequency measurements by using the super chopper design implemented on other programs at Georgia Tech as shown in Figure 8. The 35 GHz/95 GHz feed horns receive the signal from the scene (target), sky view, or internal calibration loads as selected by the data acquisition system (DAS). The signal exits via the horizontally (H) and vertically (V) polarized output ports of the orthomode transducer. Each polarized signal is down-converted in a separate mixer to an IF of nominally 2.0 to 4.0 GHz. The local oscillator signal is injected into each mixer using a directional filter.

The IF is split off using a 4-way power divider into two bandpass filters and two termination loads. These bandpass filters provide passbands of 1 GHz and 2 GHz centered on 3 GHz. The two extra ports, which are terminated, are spare paths for future growth that could be used with different bandpass filters or be used for IF correlation of the H and V channels. Square law detectors follow each bandpass filter. The detected Dicke modulated signal in each channel goes to a phase

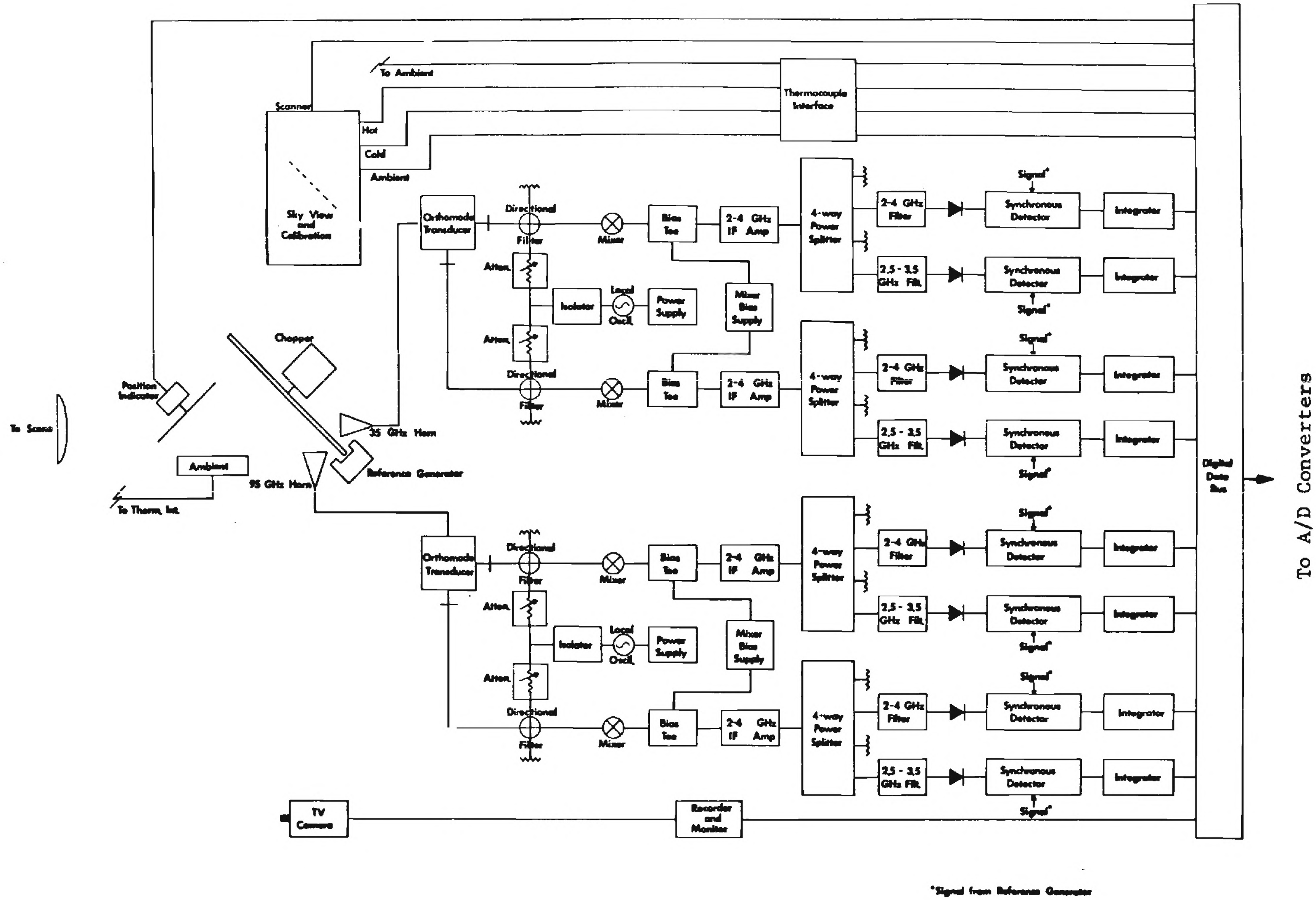


Figure 6. Block Diagram of Radiometer.

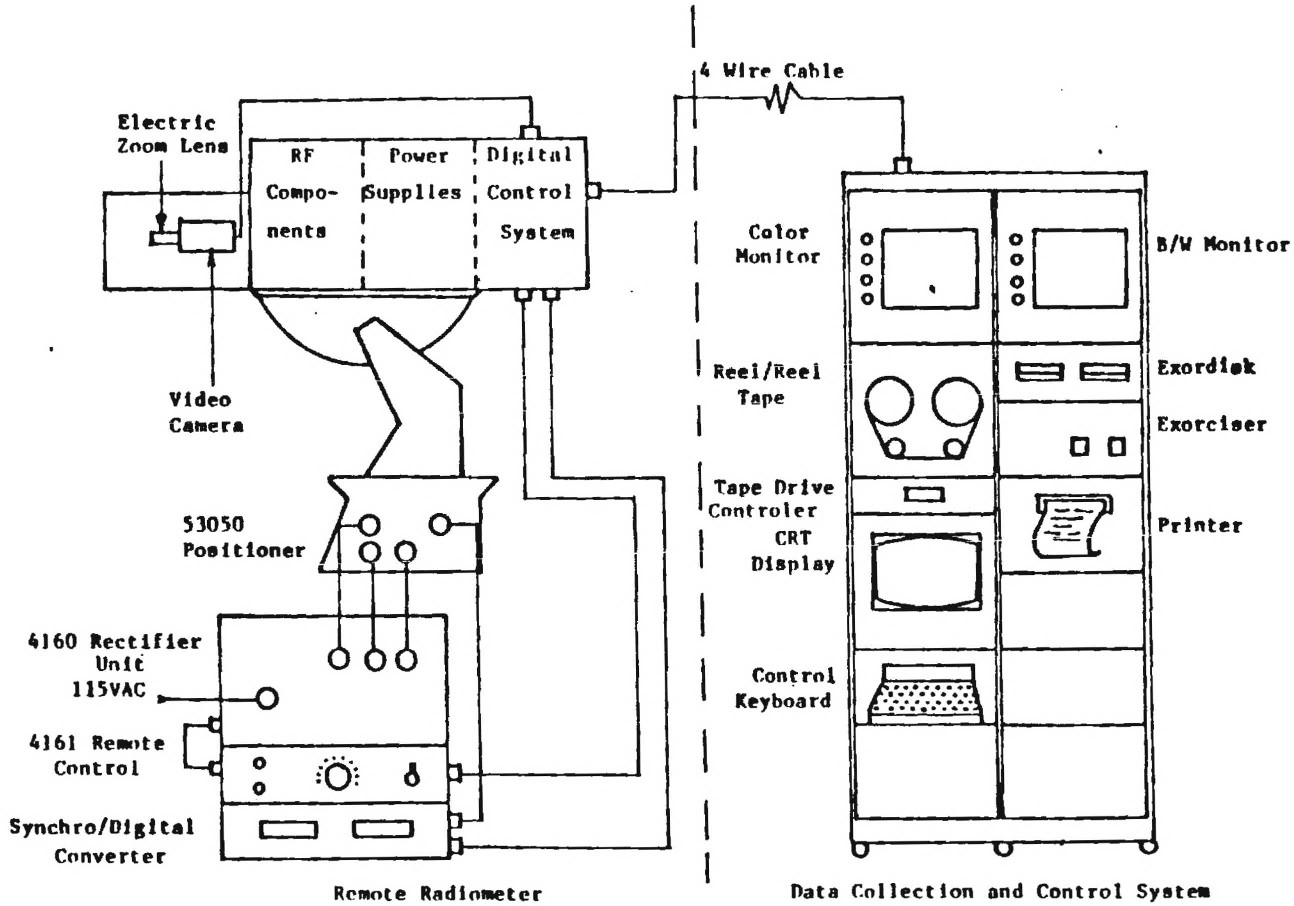
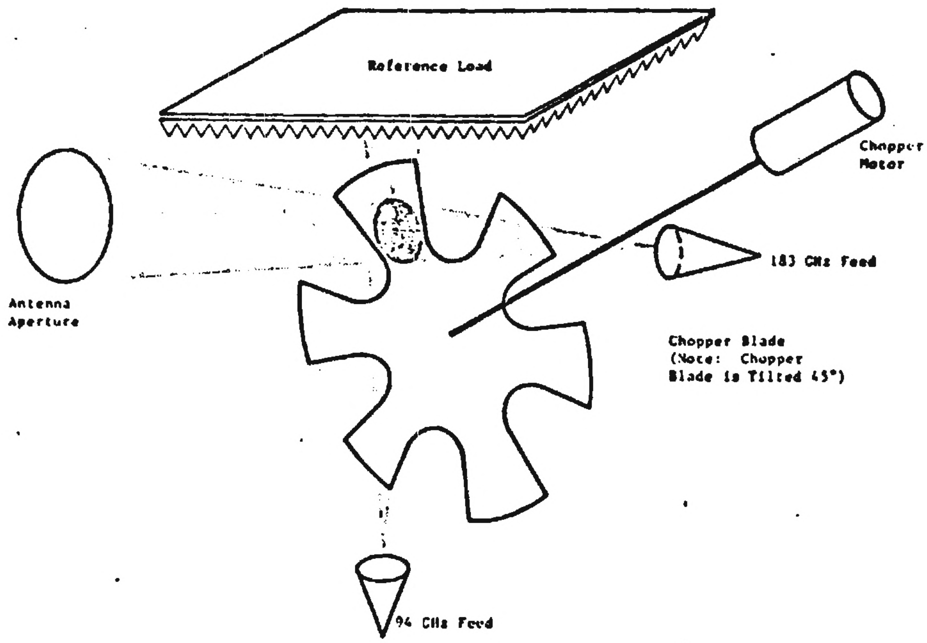
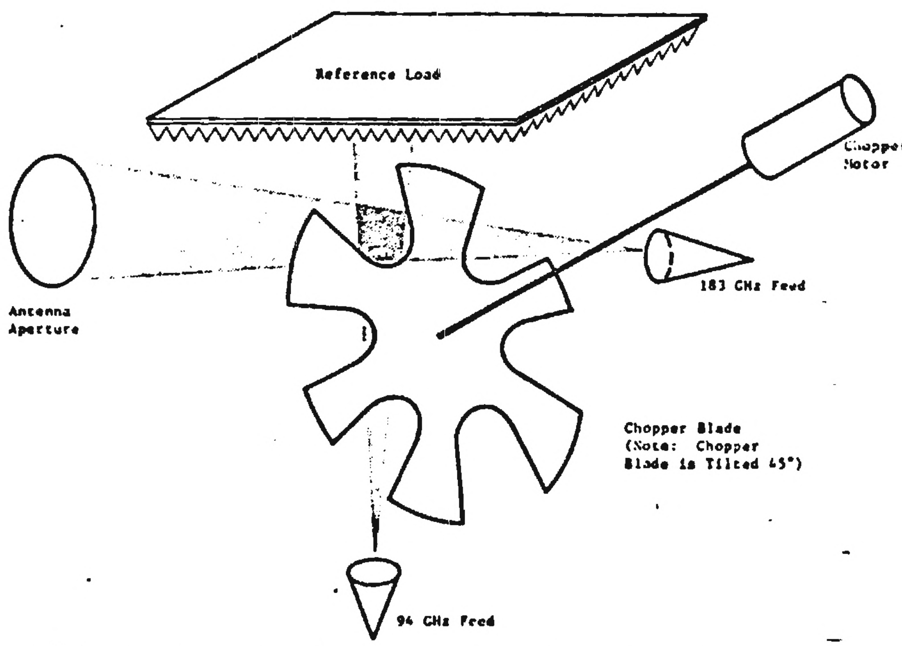


Figure 7. Millimeter-Wave Instrumentation Radiometer.



(a) Super-Chopper Concept - Shown Reflecting To Antenna At 94 GHz and Reflecting Into Reference Load at 183 GHz.



(b) Super-Chopper - Shown Transmitting To Reference Load at 94 GHz and Transmitting to Antenna at 183 GHz.

Figure 8. 94/183 GHz Radiometer Super Chopper Concept.

sensitive detector (PSD) whose input is multiplied by the super chopper reference generator. The reference signal switches the detector output in synchronization with the antenna signal so that the PSD output voltage is directly proportional to the scene temperature. The integrator is a low-pass filter having an integration time chosen to yield an acceptable temperature resolution. All integrator outputs are routed to the data acquisition system.

2.2.1 RF system

The RF portion of the radiometer consists of a dual frequency, dual polarization receiver as shown in Figure 9. The two frequencies share a common radiating aperture as well as common calibration loads. This is accomplished by integrating two feeds using the super chopper. The feeds are corrugated conical horns and are mounted orthogonal to each other so that as the chopper rotates, the feeds look alternately at the Dicke load and the scene. Since the assembly is symmetrical, no depolarization takes place. Therefore, both E_ϕ and E_θ polarization components are equally received.

A 6 inch diameter Rexolite lens, having an f/D ratio of 1, is illuminated by the horns. This lens focuses energy from the horn to a spot 6 inches from the lens so that beam switching may be easily accomplished. The focused beam can be reflected by the small switching reflector into one of the calibration loads or can be allowed to pass unblocked. The unblocked beam illuminates the 20 inch radiating aperture.

The 20 inch lens is designed to correct the phase of the incoming RF signal so that it is focused at the correct target range. Adjustments of the focal distance is accomplished by moving the 20 inch lens along the lens/horn axis. Single frequency antenna patterns measured at the focal point, in the target plane, show the antenna to have a 0.4 degree 3 dB beamwidth at 95 GHz and sidelobes greater than 24 dB below the peak signal. The 35 GHz pattern exhibits the same sidelobe structure but has a 3 dB beamwidth of 1.3 degrees.

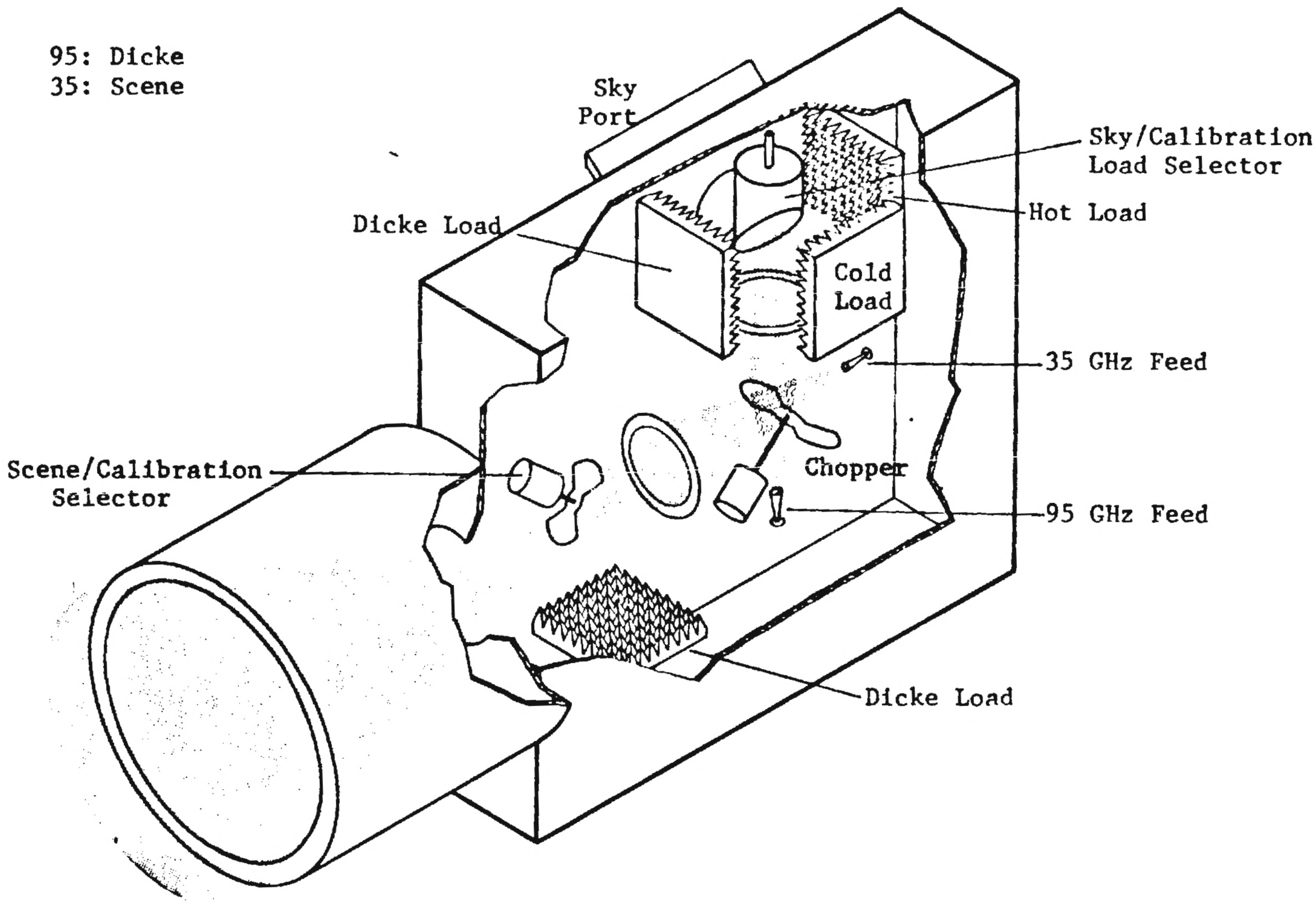


Figure 9. RF Portion of Radiometer.

Signals received by the corrugated conical horns are transmitted to a waveguide orthomode coupler where they are split into E_ϕ and E_θ polarization components. These signals are down-converted to the 2-4 GHz IF band. A coupling device other than the standard directional coupler is required so as to keep the losses in the mixer chain low, while providing low insertion loss for the local oscillator signal. The coupling device used in this radiometer is actually a directional filter (having a very small range of frequencies) such that transmission can occur at the LO frequency. Outside this frequency range the input signal bypasses the coupling structure resulting in negligible losses at the signal frequency.

One of the antenna feeds shown in Figure 9 views an ambient temperature load, used as the Dicke reference, while the other feed views either a scene with an unknown temperature (data mode) or a known temperature reference load (calibration mode). During data collection the lower port views the scene through the large lens while the upper port views the Dicke reference load. For calibration the lower port is reflected to view the second Dicke reference load. The upper port views the sky (via the sky reflector), the hot load, the cold load, and the upper Dicke reference load. Both the upper and lower reflectors are positioned by stepper motors under microcomputer control.

The calibration and reference loads consist of pyramids made with an absorbing material adequate for both polarizations. The pyramids are cut at the Brewster angle to minimize reflections. The hot load is temperature controlled with heating elements and the cold load is cooled with liquid nitrogen. The cold load temperature is monitored by thermistors routed thru a multiplexor to the computer. Thermistors are also used to measure the operating temperature of several major RF components including the large lens.

2.2.2 IF/Video System

The IF/Video portion of the radiometer consists of the IF amplifiers, filters, square law detectors, video amps, and phase sensitive detectors. The IF section is identical for each of the four frequency and polarization combinations. The IF signal is nominally 2.0 to 4.0 GHz. It is amplified by two IF amplifiers each of which provides approximately 35 dB of gain. The amplifier output is fed into a four-way power splitter. Two ports of the power splitter are terminated in matched loads providing spare paths for possible future growth. The other two ports feed bandpass filters with passbands of 1 GHz and 2 GHz centered on 3 GHz. The 1 GHz filter has 9 elements giving a very steep rolloff outside the passband. The 2 GHz filter has 2 elements giving a less steep rolloff characteristic. Each filter is followed by a Schottky diode square law detector.

The detected Dicke modulated signal goes to a video amplifier having a voltage gain of 2000. This signal is fed to the phase sensitive detector (PSD). The first stage of the PSD is a high Q bandpass filter centered on the Dicke chopping frequency. This signal is multiplied with the chopper reference signal giving a full wave rectified signal with a voltage directly proportional to the scene temperature. The signal is then integrated by a low-pass filter having an integration time of approximately 0.25 seconds. At this point the signal is a dc voltage directly proportional to the scene temperature. The integrator output is routed to the data acquisition system.

2.2.3 Radiometer Auxiliary Equipment

Radiometer auxiliary equipment includes the antenna positioner and associated controls, the television camera, and the turntable controls. A Scientific Atlanta 54050 antenna positioner was used to rotate the radiometer during the measurements at Georgia Tech and NSTL. The 54050 positioner is an elevation-over-azimuth unit that allows the measurement of true vertical and horizontal polarization.

The positioner is controlled by the microcomputer via a Georgia Tech built interface. The computer sends an axis selection, a direction selection, and a speed voltage to the interface which routes these signals to the positioner. Each axis of the positioner has two synchro position indicators (a 1:1 and a 36:1). The computer-positioner interface converts the synchro outputs to binary coded decimal angles and routes these signals to the computer. The angle readouts are to .01 degrees and the positioner is positioned to 0.10 (+ 0.09/-0.00) degree accuracy.

A television camera is used to provide a record of the scene imaged by the radiometer and also to set up the limits of scan patterns. The camera is initially aligned with the center of the field-of-view of the radiometer antenna. After the transmitter is centered in the field-of-view of the radiometer, the camera lens is adjusted to the same field-of-view. The image of the transmitting antenna is then brought into view of the camera by adjusting the camera mount alignment with respect to the radiometer. The camera mount provides a rigid support to maintain this initial alignment. The television camera's iris opening, focus, and zoom lens are controlled from the operator's console via the computer. The camera field-of-view can thus be matched to the radiometer field-of-view and the iris can be adjusted to cope with changing light conditions.

2.3 Radiometer Data Acquisition System

The radiometer data acquisition system consists of two major units under the control of separate microprocessors. The first unit, known as the Radiometer Interface Processor (RIP), is located within the radiometer enclosure and provides the link between the analog radiometer hardware and the other unit. The second unit, known as the Data Collection Processor (DCP), is located in a dual rack assembly which can be separated up to 300 feet from the radiometer. The DCP contains the receiver for the RIP output and the transmitter for commands. Radiometric and calibration data from sensors in the radiometer are digitized by the RIP and passed to the DCP which records the data on magnetic tape. Control signals from the DCP are routed to the radiometer by the RIP so as to operate the two-axis positioner, control the chopper and stepper motors, and to calibrate the radiometer. Figure 10 is a photograph of the DCP used during the measurements.

The data acquisition system insures that target data is recorded reliably and accurately in a form that will simplify analysis on a computer. The software and hardware of the radiometer data acquisition system allowed unattended operation during the actual measurements and insured the quality and integrity of the data. Among the functions automated by the data acquisition system were the scanning of the external tank scene raster by the radiometer. An algorithm was formulated to compute all the locations where sampling would occur from three sets of input coordinates representing the size and centroid depression angle of the desired raster frame.

2.3.1 Data Acquisition Components

The RIP performs three major functions: 1) convert analog outputs from the eight radiometer channels and 12 thermistors into digital data, 2) accept commands from the DCP to control the movement of the calibration reflectors, antenna positioner, and zoom lens, and 3) send digital data and status data to the DCP for recording.

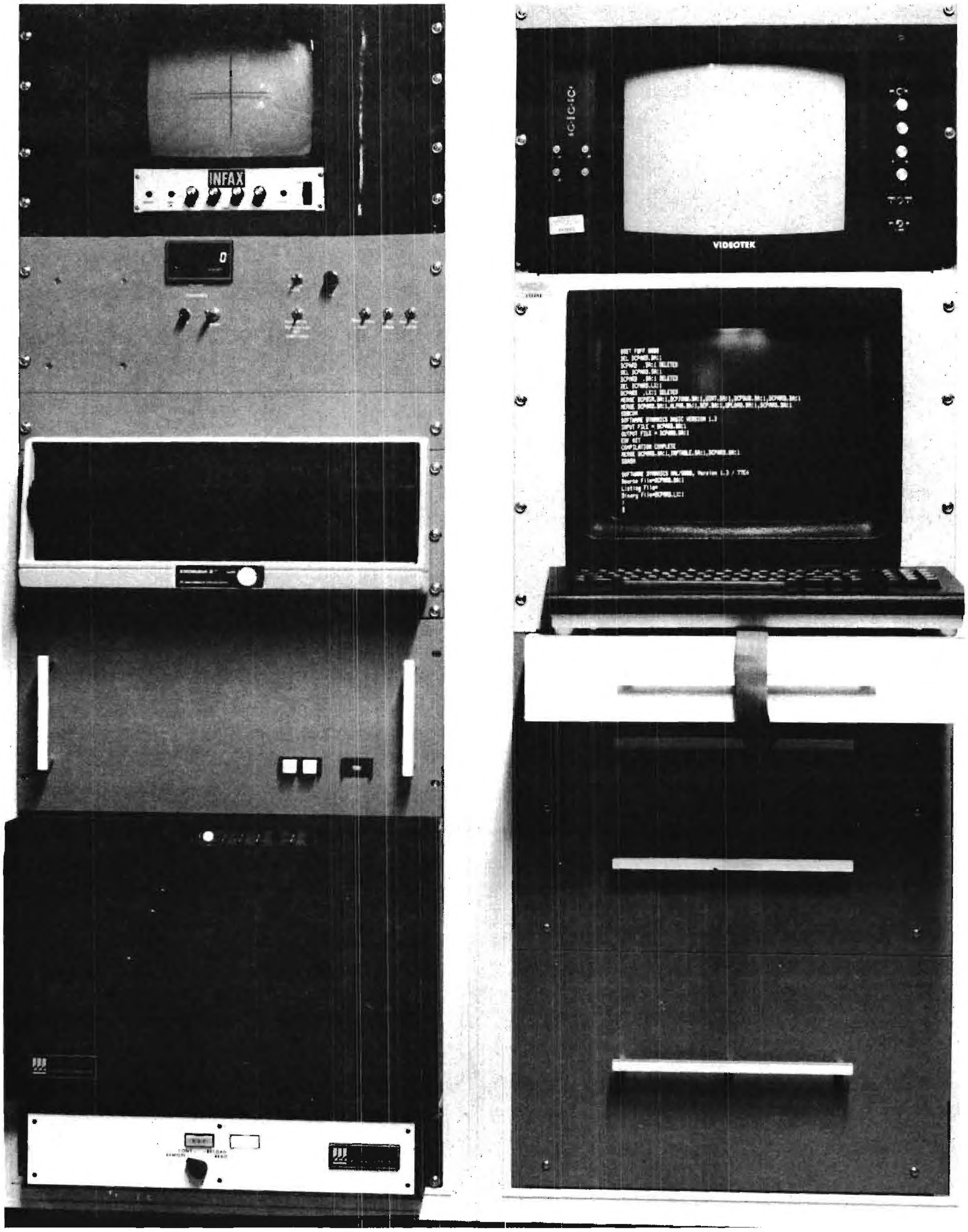


Figure 10. Photograph of Georgia Tech Radiometer's Data Collection Processor (DCP).

The RIP utilizes a Motorola Micromodule 1A microcomputer, an 8 bit microprocessor (M6802), 16 K bytes of random access memory, and hardware interfaces. All functions of the system are controlled by programs written in assembly and basic languages and are executed by the microprocessor. The analog radiometric signals are converted to a digital form by a 16 channel multiplexer - A/D converter with 12 bit resolution. The antenna positioner interface converts digital angle data from the microcomputer into synchro drive signals compatible with Scientific Atlanta positioners. It also converts synchro angle data from the positioner into digital form for use by the RIP microcomputer.

A GBC-ITC model CTC-5000C transistorized black-and-white TV camera was used to allow correlation between measured target temperatures and actual target geometry for the external tank measurements. A Vicon motorized zoom lens with remote control was modified to allow control by the RIP microcomputer. Commands were available to control the iris, zoom, and focus. By controlling the field-of-view, the entire target or portions could be examined as measurements occurred. The calibration reflector motors and switches were controlled by the RIP microcomputer through optically isolated, high current drivers in the digital control interface. Feedback allowed the microcomputer to sense the position of the calibration reflectors.

The DCP's primary purposes were: 1) to act as the interface between the operator and the RIP and 2) to control the collection and recording of ice signature data on magnetic tape for later analysis. In addition, the DCP controlled a number of supporting peripherals. The DCP uses a Motorola EXORciser 1A microcomputer. The EXORciser includes an 8 bit microprocessor (6800), 48K bytes of random access memory, interfaces to drive the disk drive, CRT terminal, graphics display, tape drive, printer, and to communicate with the RIP. All these functions were controlled by programs written in assembly and Basic languages and executed by the microprocessor. A dual drive floppy disk system, the Motorola EXORdisk II, provides 500K bytes of on-line mass storage for the data acquisition system. This device allowed permanent storage of the operating system software and also was used for temporary storage of radiometric data prior to being formatted for writing on magnetic tape.

The operator header information, the video image, and the ice signature and calibration data were recorded on magnetic tape. All data tapes produced on the 35/95 GHz instrumentation radiometer data collection processor conform to the ANSII standard for reel-to-reel 1/2" magnetic tapes. The particular equipment utilized to record these tapes is a Digi-Data Corp. Model 1639 transport and a Digi-Data Model LP-PE-9H2 dual buffer/formatter. Data was recorded in nine track, 1600 bits per inch, phase encoded IBM compatible format on a 8-1/2" reel. All tape records are a fixed length of 1024 bytes. Approximately 12 megabytes of storage capacity are available per one 8-1/2" reel.

Graphical representations of the ET surface were displayed on a video monitor driver by a graphics generator. The format of the display was controlled by appropriate software in the DCP microcomputer. A resolution of 256 x 256 points with a 16 level gray or color scale was provided. A black and white image of the target was digitized and stored to allow correlation between measured ET target temperatures and actual ET target geometry. A CRT terminal was used to provide an interface between the operator and the data acquisition system. The operation of the radiometer was controlled by commands entered via the CRT terminal keyboard and all messages from the system were displayed on the terminal. A time of day clock with battery backup power provided the current date and time to the nearest second for the microcomputer. This time information was needed for scan sequencing timing. The clock was set via commands from the CRT terminal.

2.3.2 RIP Software Description

The radiometer interface processor (RIP) software is a BASIC-language program which implements commands from the data collection processor (DCP) and sends data back to the DCP. The software consists of five main sections - initialization routine, the main program, command execution subroutines, input-output routines, and interrupt service routines. The initialization routine is executed once at the beginning of the program. It initializes all variables and memory locations to the proper values. The main program receives commands from the DCP and decodes them. It then transfers control to the correct subroutine for execution of that command. After the command has been implemented, the command is echoed to the DCP and the program is ready to go on to the next command.

The command execution subroutines are called by the main program or other subroutines and implement the various functions of the radiometer. These routines control the reflector positioning motors, the zoom lens functions, the antenna positioner, and the analog to digital converter. There are also subroutines to execute a scan and to perform a calibration. After implementing the command, program control is returned to the main program or the calling subroutine.

The input-output routines control data transmission and reception through a two-way serial link between the RIP and the DCP. There are two types of routines in this section. The primitive routines control data on a single character level. The other routines handle formatted data. The last section of the software contains the interrupt service routines. There are two types of interrupts, both of which are routed through the main program. An interrupt from the DCP will cause the transmission of the output data buffer when this interrupt is enabled. An interrupt from the antenna positioner results in an update of the appropriate angle. During data collection this interrupt also causes a check for a valid data point and collection of the radiometer channel voltages if the angle is valid.

2.3.3 DCP Software Description

The DCP software is a combination of BASIC and assembly language programs. It can be separated into two major areas, 1) implement commands from the operator to execute a data scan and record the gathered data and 2) analyze the recorded data to verify proper operation of the radiometer.

The initialization routine is executed at the beginning of the program. It initializes all variables for the DCP software and accepts commands from the operator. The adjust positioner and camera routine instructs the operator to position the radiometer to the center of the target and set the field of view and focus of the B/W camera through panel switches. The appropriate commands are relayed to the RIP. The actual position (angles) of the radiometer is saved for reference and a digitized B/W image is recorded. The operator is instructed to move the positioner to the top center, then to the left center of the target area. Using the operator-generated target parameters, the appropriate pattern points are calculated to provide the proper sampling of the target.

The operator is asked to input target characteristics, weather conditions, and other items perculiar to a particular target scene. This information is recorded on magnetic tape. The RIP is then initialized to execute the desired pattern. Any necessary angular parameters are displayed on the CRT. An initial calibration is performed at this time and the data is collected. The RIP is then commanded to scan one line of the target. From the pattern points, radiometric data from the PSD outputs are gathered and stored. If necessary, depending on a user entered option, a calibration of the radiometer is performed and the data is collected. The radiometric and calibration data from the scan is then formatted, packed, and recorded on magnetic tape.

The quick-look analysis software checks to verify proper operation of the radiometer. First, the tape is read, the header information is printed on the console, and the black and white video image is displayed on the monitor. Following this, the initial calibration information is read, converted to both volts and temperature, and displayed on the console. Finally, using the calibration information, the radiometric data is analyzed, mapped onto a pseudo color scale, and displayed on the color monitor.

3.0 Ice/Frost Signature Data Measurements

3.1 Phase 1a Program (Georgia Tech Tests)

The target used for the ice/frost data collected at Georgia Tech consisted of an ET SOFI sample attached to an aluminum substrate and conditioned to simulate ET cryogenic temperatures. For ease of operation the substrate was conditioned with LN_2 and the SOFI thickness was varied to enable ice/frost accumulations in the test enclosure. The foam-covered aluminum test panel was attached to an aluminum subpanel which was cooled with LN_2. The target was originally constructed with a transparent front, made of plexiglass, to allow viewing of the target panel from outside. During the day, however, incident sunlight trapped by the plexiglass cover kept the test panel too warm for ice to form. The plexiglass was replaced with one inch-thick styrofoam insulation with good success.

Four surface conditions for the target sample were considered for these measurements. They were dry, wet, frost and ice. A dry target was one where no moisture, frost or ice was present on the target or insulating enclosure. A dry condition was obtained at the beginning of each measurement period by opening the enclosure to the high ambient temperature and to strong incident sunlight. Water was sprayed onto the dry target to form a wet target. A uniform layer of water was applied and a wet target was obtained by closing the insulating doors to prevent rapid evaporation.

Frost and ice formation presented a more difficult task. LN_2 was pumped into a reservoir which included the aluminum sub-panel as a wall. The gaseous nitrogen was bled off by a vent from the interior of the test enclosure. The low temperature of the nitrogen exhaust cooled the surface of the foam sufficiently to allow frost to form. When the reservoir had been filled with LN_2, the target surface was placed horizontal with the SOFI facing upward. Water was poured onto the SOFI and the insulating doors were closed. The chamber was then subject to extremely rapid cooling of the air by pumping LN_2 directly into the chamber. The extremely cold ambient air froze the water directly onto the foam, forming a nearly-uniform layer of ice. The target was then positioned to the correct angle for measurements. Ice, once formed, was maintained by the cooling effect of the LN_2 bleed off routed into the chamber. This process was repeated as often as necessary to obtain a specified thickness of ice.

The beamwidth, θ_B, of the Georgia Tech 95 GHz instrumentation radiometer is approximately 0.4 degrees. The beam spot diameter, d, on the target is given by:

$$d = R\theta_B\ (\pi/180) = 0.4R\ (\pi/180) = 6.98 \times 10^{-3}\ R$$

where R is the distance between the radiometer's lens and the target. R varying from 50 to 200 feet yielded beam spot diameters from 4.2 to 16.8 inches. The radiometer output was sampled four times per beamwidth, or once every 0.1 degree. The target size was 3 feet by 3 feet and measurements were made with the target rotated along a horizontal axis for various target deflection angles. Below is a summary of the beam spot diameter (d), the number of beams per target width, and the number of samples per scan line on the target for R = 50 feet and 200 feet.

R, feet	d, inches	Beamwidths/Target Width	# Samples/Azimuth Scan
50	4.2	8.6	34.4
200	16.8	2.1	8.6

During the course of the Georgia Tech measurements program, many scans of the target were made in order to depict a variety of target and environmental conditions. Table 4 is a summary of the data collected during the ice measurements at Georgia Tech. The target view angle is that angle between the line of sight from the radiometer to the target and the normal line from the target surface. The sky temperatures shown are the radiometric temperatures of the sky recorded at the beginning (1), the middle (2), and the end (3) of the scan. The coldest pixel temperatures refer to the lowest pixel temperature in the scan for the reference plate and for the target plate. The reference plate (aluminum sheet) was scanned concurrently with the sample target to compensate for

Table 4

Summary of Scan Data

Test	Target View Angle	Sky Temperatures 1	2	3	Coldest Pixel Temperatures Reference	Target	Ref. Avg. $\overline{R}$	Targ. Avg. $\overline{T}$	Differences T-R	$\overline{T}-\overline{R}$	Polarization	Ice Thickness	Cloud Cover Estimate	Comments
1	30°	130	128	122	167	196	179	211	29	32	Vertical	1/8"	50%	1/4" SOFI, doors, 200 feet Run # 20, Channel # Ø
2	30°	128	125	121	161	205	172	212	44	40	Horizontal	1/8"	50%	1/4" SOFI, doors, 200 feet Run # 20, Channel # 3
3	30°	73	77	78	120	125	132	136	5	4	Vertical	Dry	10%	1/4" SOFI, doors, 200 feet Run # 35, Channel # Ø
4	30°	72	72	74	89	102	108	108	13	0	Horizontal	Dry	10%	1/4" SOFI, doors, 200 feet Run # 35, Channel # 3
5	60°	145	153	145	205	228	213	238	23	25	Vertical	1/8"	90%	1/4" SOFI, doors, 200 feet Run # 21, Channel # Ø
6	60°	145	151	143	206	230	211	240	24	29	Horizontal	1/8"	90%	1/4" SOFI, doors, 200 feet Run # 21, Channel # 3
7	60°	76	75	78	183	196	206	220	13	14	Vertical	Dry	10%	1/4" SOFI, doors, 200 feet Run # 36, Channel # Ø
8	60°	72	74	76	177	192	196	206	15	10	Horizontal	Dry	10%	1/4" SOFI, doors, 200 feet Run # 36, Channel # 3
9	45°	157	130	130	159	163	170	173	4	3	Vertical	Dry	60%	1/4" SOFI, 200 feet Run # 14, Channel # Ø
10	45°	152	126	128	159	166	177	180	7	3	Horizontal	Dry	60%	1/4" SOFI, 200 feet Run # 14, Channel # 3
11	45°	128	127	130	146	195	165	210	46	45	Vertical	1/8"	40%	1/4" SOFI, doors, 200 feet Run # 19, Channel Ø
12	45°	126	127	128	150	201	162	211	51	49	Horizontal	1/8"	40%	1/4" SOFI, doors, 200 feet Run # 19, Channel # 3
13	45°	92	96	92	126	140	149	156	14	7	Vertical	Dry	5%	1/4" SOFI, Doors, 200 feet Run # 30, Channel # Ø
14	45°	90	95	89	114	130	134	149	16	15	Horizontal	Dry	5%	1/4" SOFI, Doors, 200 feet Run # 30, Channel # 3
15	45°	100	106	102	119	151	143	161	32	18	Vertical	1/16"	50%	1/4" SOFI, Doors, 200 feet Run # 33, Channel Ø
16	45°	97	103	99	130	155	146	168	25	22	Horizontal	1/16"	50%	1/4" SOFI, Doors, 200 feet Run # 33, Channel # 3

Note: All temperatures are in degrees Kelvin.

sky temperature variations during the scans. The averages of nine pixels in a 3 x 3 pixel square at the centers of the radiometric image of the reference ($\bar{R}$) and the target ($\bar{T}$) are computed and listed. The differences are computed between the coldest temperatures for the target and the reference shown as (T-R) and for their averages shown as ($\bar{T}$ - $\bar{R}$). The thickness of the ice, or its absence, is listed, followed by the percentage of cloud cover observed during the scan. Under comments, the thickness of the Spray-On-Foam Insulation (SOFI) on the target is listed; "doors" indicate the presence of one inch thick styrofoam doors over the target; and the run and channel numbers are given as a source to refer back to the original data for future analysis.

3.2 Phase 1b Program (NSTL Tests - Dec. 1980 & Jan. 1981)

Based on the Georgia Tech ice measurements using the ET target samples, the next measurements called for ice/frost detection on the shuttle external tank during actual cryogenic loading operations. The site for these measurements was at NASA's National Space Test Laboratory (NSTL) near Bay St. Louis, MS where the orbiter engine static firing tests were held. Reference targets located on the test stand were scanned concurrently with the ET in order to compensate for the variation in the background sky. One reference target was an aluminum sheet of 1/16 inch thickness with approximate dimensions of 4 feet by 8 feet. The second reference target was an aluminum sheet covered with SOFI and located adjacent to the metal target. Both reference targets were tilted about 15° upward toward the sky in order to provide an acceptable angle of sky reflection. Figure 11 is a photograph showing both targets on the test stand.

The 95 GHz radiometer used for NSTL measurements has a 20 inch diameter (D) lens resulting in a 0.4° half power beamwidth (θ_B°) at 95 GHz. The beam spot diameter, d, on the ET surface at a distance R from the radiometer was previously shown to be:

$$d = R\,\theta_B^{\circ}\left(\frac{\pi}{180}\right).$$

Table 5 summarizes the spatial resolution for the 95 GHz radiometer used for the measurements at NSTL. At a distance of 450 feet the beam spot diameter was 3.14 feet. This resulted in approximately nine beamspots across the 28 foot diameter ET target at a distance of 450 feet. Table 5 also shows the number of beam spots per scan across the external tank as a function of range R.

The measurement program at NSTL required additional support for the Georgia Tech radiometer and operating personnel. The basic facility support included the following:

1) A forklift was required to maneuver the radiometer instrument onto the antenna positioner;
2) A supply of liquid nitrogen of about 160 liters per day was used for the radiometer's cooled calibration loads;

Figure 11. Radiometric Reference Targets Used at NSTL During 95 GHz Ice Measurements.

Table 5

95 GHz Radiometer Spatial Resolution Data For
ET Scan at NSTL

R (feet)	d (feet)	Beam spots/scan cross ET
200	1.40	20.0
250	1.75	16.0
300	2.09	13.4
350	2.44	11.5
400	2.79	10.0
450*	3.14	8.9
500	3.49	8.0

*Approximate distance between ET and Georgia Tech radiometer site for all tests at NSTL.

3) A 4 by 8 foot aluminum plate of 1/16 inch thickness was provided to serve as the secondary reference target and was mounted near the ET LOX tank on the tower;

4) Electrical power requirements for the radiometer system of 110 Vac, 60 Hz, 50 amperes maximum were provided during the NSTL tests.

During the January 1981 NSTL tests Georgia Tech requested that NASA provide a cut-out section of 1 meter square on the LOX tank. This was requested to allow a better opportunity for ice to form on the ET where the SOFI thickness was reduced. The thickness of the SOFI was reduced to 1/2 inch in the cut-out area. Figure 12 is a close-up view of this area. Following the loading of the ET with liquid oxygen and liquid hydrogen, Georgia Tech personnel sprayed the cut-out area with freon and water to form ice. This region was scanned continuously with the remaining ET target where no ice was seen. The total scan sequence included 1 hour of data prior to ET loading, 5.5 hours of data taken with the tank partially or fully loaded, and 1.5 hours of data collected immediately after engine firing.

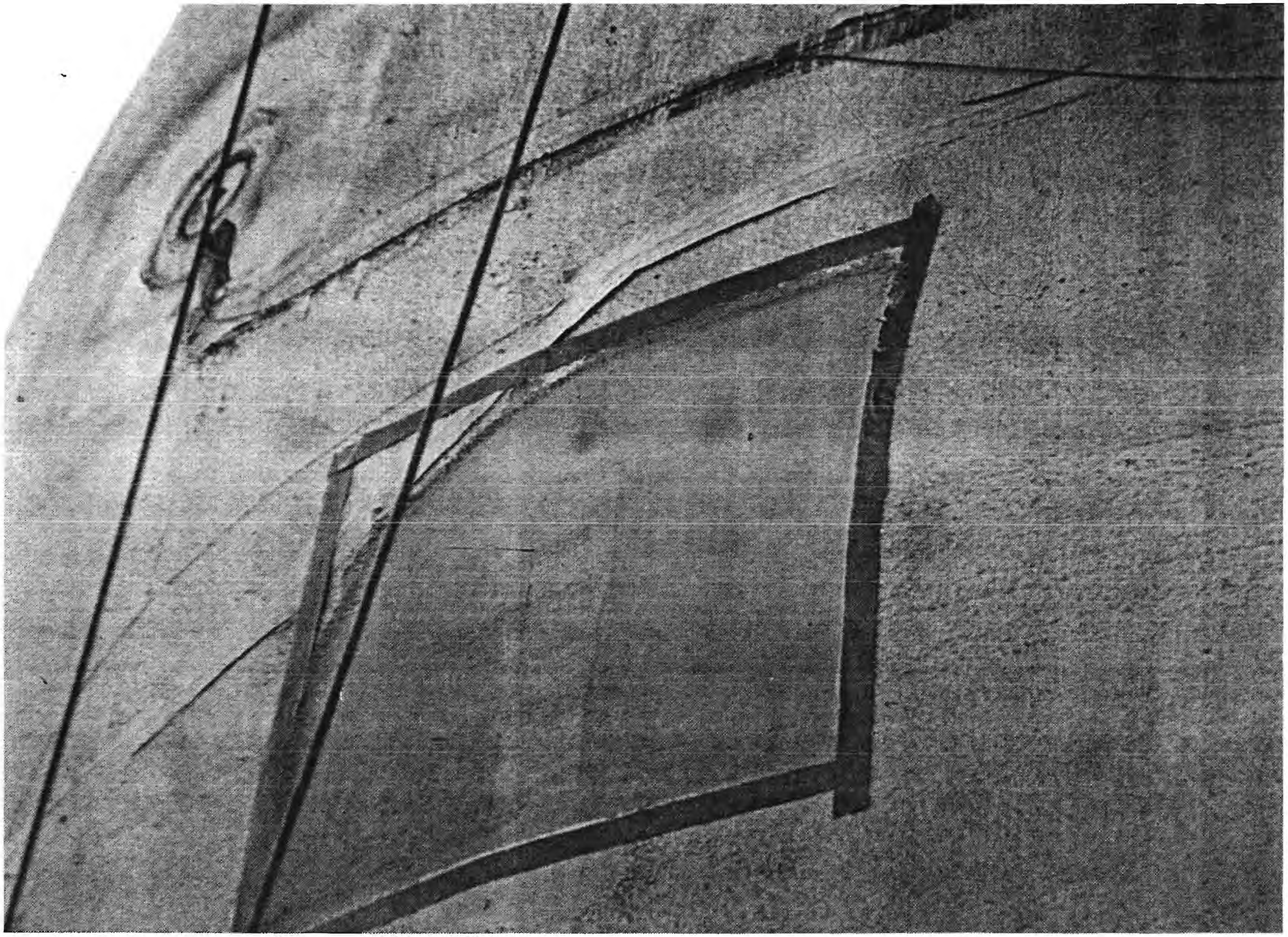


Figure 12. Close-up View of 1 Meter Square Cut-out Section Located on ET LOX Tank.

4.0 Ice/Frost Signature Data Analysis

4.1 Phase 1a Data (Georgia Tech Tests)

The objective for analyzing this data was to determine the effect of ice formation on the ET simulation target. Scans were compared for similar data runs with and without ice present on the target sample. A summary of the effects of ice is given in Table 6. For example test 1 (with ice) and test 3 (without ice) can be compared since both were performed at a target view angle of 30° and both represent vertical polarization data. The simplest comparison between the two test scans is to compare the temperature differences between the reference and target of each of the scans. As shown in Table 6 the presence of ice caused the target to increase in radiometric temperature by 24°K for the coldest spot, and by 28°K for the average of nine pixels. This indicates a definite warming of the target when ice is present as further shown by an increase of over 40 degrees Kelvin for other test comparisons.

A variety of data processing techniques were performed at Georgia Tech on the ice signatures collected from the SOFI target samples. Figure 13 is a pixel temperature contour plot taken from run #14, data channel #0 during which a scan was made of a dry ET target sample. For this run the average pixel temperature difference between the dry SOFI covered target and the reference metal target was only 3°K. The reference target is plotted to the left and the ET target is plotted to the right. The separation distance between pixels for this data run is approximately 0.35 feet (4.2 inches). For the 3 by 3 foot ET target this represents a matrix of about 8 by 8 pixels on the temperature contour map. For this run the target was located approximately 200 feet from the radiometer with a target viewing angle of 45°. Following the dry target run, the SOFI target sample was cooled down inside the liquid nitrogen enclosure until a 1/8 inch ice layer thickness was formed. The temperature contour map, shown in Figure 14, is for Run #19, data channel #0. The average pixel temperature difference between the ice covered ET target sample and the reference target shows an increase of

Table 6

Summary of Effects of Ice

View Angle	Polarization	Ice Thickness	Temperature Change Due to Ice Coldest Pixel (T-R)ICE - (T-R)DRY	 Center Average $(\overline{T}-\overline{R})$ICE - $(\overline{T}-\overline{R})$DRY	Test Compared (See Table 4) Ice	 Dry
30°	Vertical	1/8"	24	28	1	3
30°	Horizontal	1/8"	31	40	2	4
60°	Vertical	1/8"	10	11	5	7
60°	Horizontal	1/8"	9	19	6	8
45°	Vertical	1/8"	42	42	11	9
45°	Horizontal	1/8"	42	46	12	10
45°	Vertical	1/16"	18	11	15	13
45°	Horizontal	1/16"	9	7	16	14

Note: All temperatures are in degrees Kelvin.

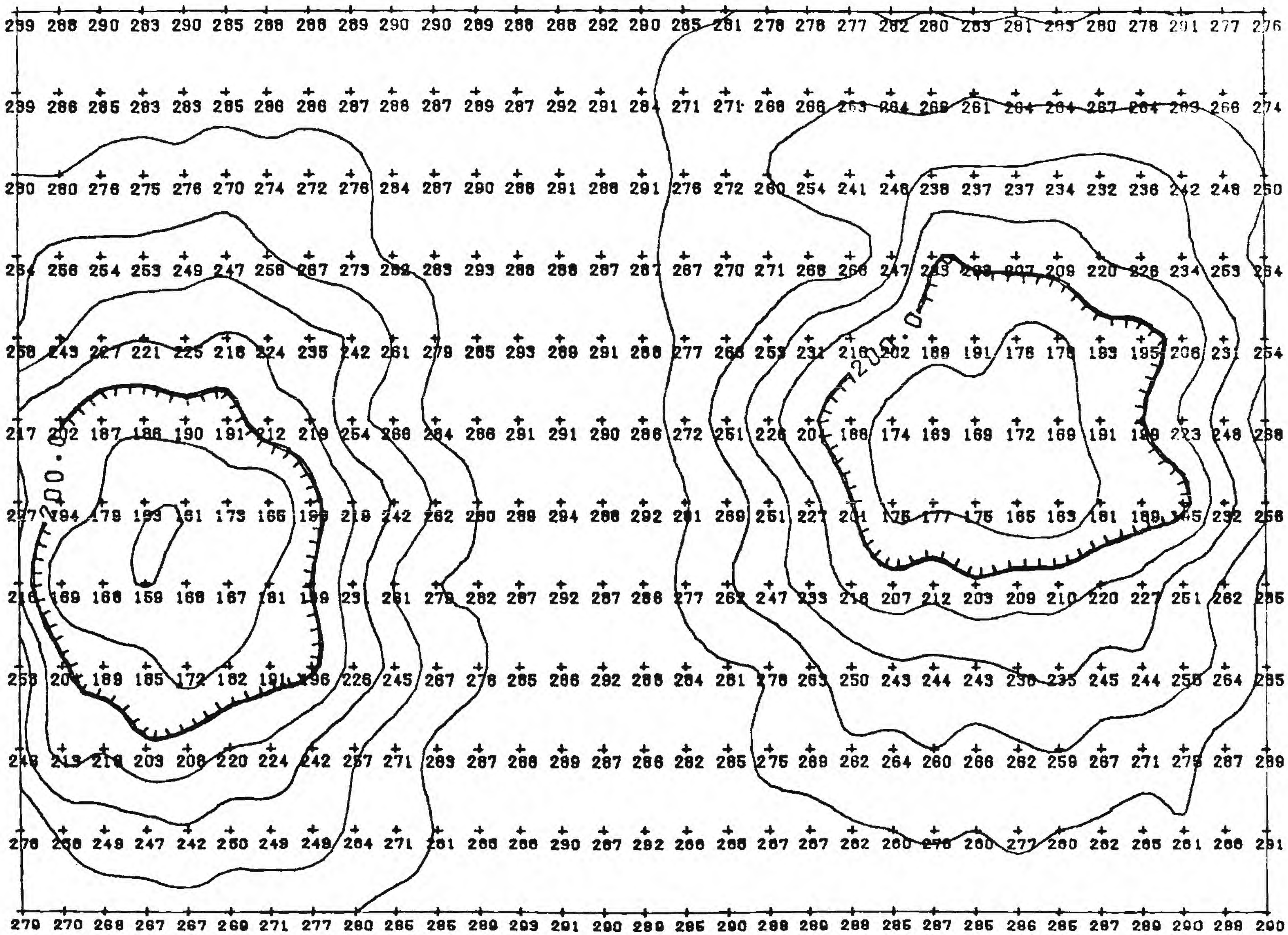


Figure 13. 95 GHz Pixel Temperature Contour Plot for Run #14, Channel #0 with Reference Target on Left and ET Target (Dry) on Right.

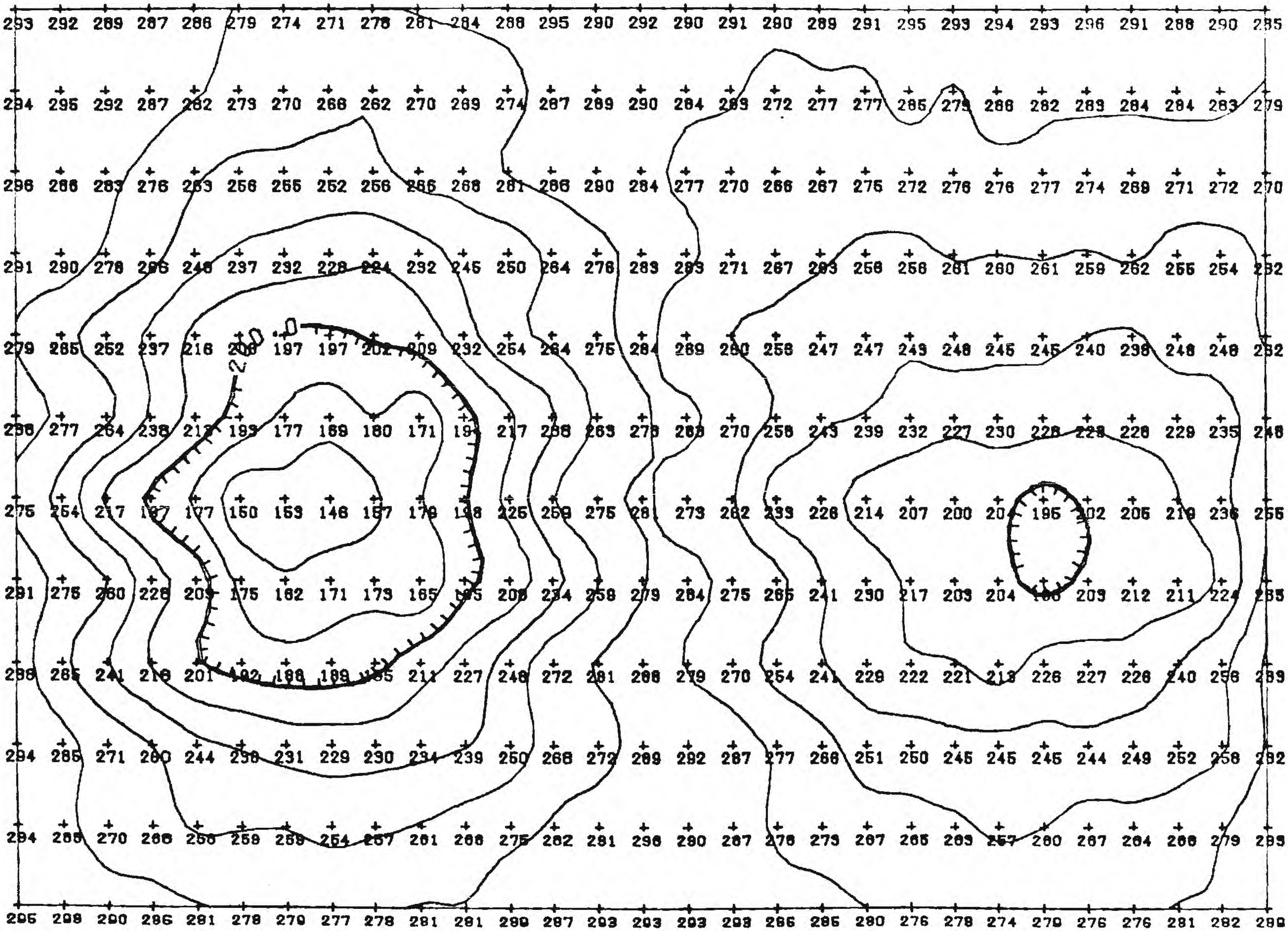


Figure 14. 95 GHz Pixel Temperature Contour Plot for Run #19, Channel #0 with Reference Target on Left and ET Target (with Ice) on Right.

45°K indicating that the ET target's apparent temperature rose approximately 42°K when covered with ice.

Figure 15 is a radiometric scanned image at 95 GHz of the scene showing the reference target on the left and the dry ET target sample on the right. This image is of the same data run #14, Channel #0 described above. The color breakpoints for the image were set with dark blue as the coldest temperature displayed and light blue as the warmest temperature. Figure 16 is the radiometric image of the target following ice formation of approximately 1/8 inch thickness on the target sample. The ET target appears warmer (pinkish color) due to the presence of ice.

Another technique used to compare the sets of data (with and without ice) was the generation at Georgia Tech of three dimensional plots of the data array. Again a comparison is made between run #14 (dry target) and run #19 (ice layered target) using the pictorial information as shown in Figures 17 and 18. For these plots the reference target is shown on the left and the ET sample is on the right. The decrease in the height of the ET sample plot is indicative of an increase in the radiometric temperature due to ice being present.

4.2 Phase 1b Data (NSTL Tests - Dec. 1980 & Jan. 1981)

The data gathered during the NSTL tests provided a good data base for the signature analysis because of the availability of an actual external tank fully loaded with cryogenics. The location of the radiometer, within 450 feet of the ET, provided good spatial resolution needed for the generation of radiometric images of the target. The control test of forming ice on the cut-out section (with reduced SOFI thickness) offered a comparison of ice data and dry target data using processing techniques developed at Georgia Tech.

Figure 19 is a collection of 95 GHz radiometric images (16) of the ET LOX section in which eight hours of continuous scans were performed beginning with pre-loading of cryogenics and ending with post-firing of the orbiter engines. Each of the 16 images shown represent a 30 minute scan of the ET and includes the cut-out area with SOFI thickness reduced to approximately 1/2-inch. Table 7 provides a legend for each

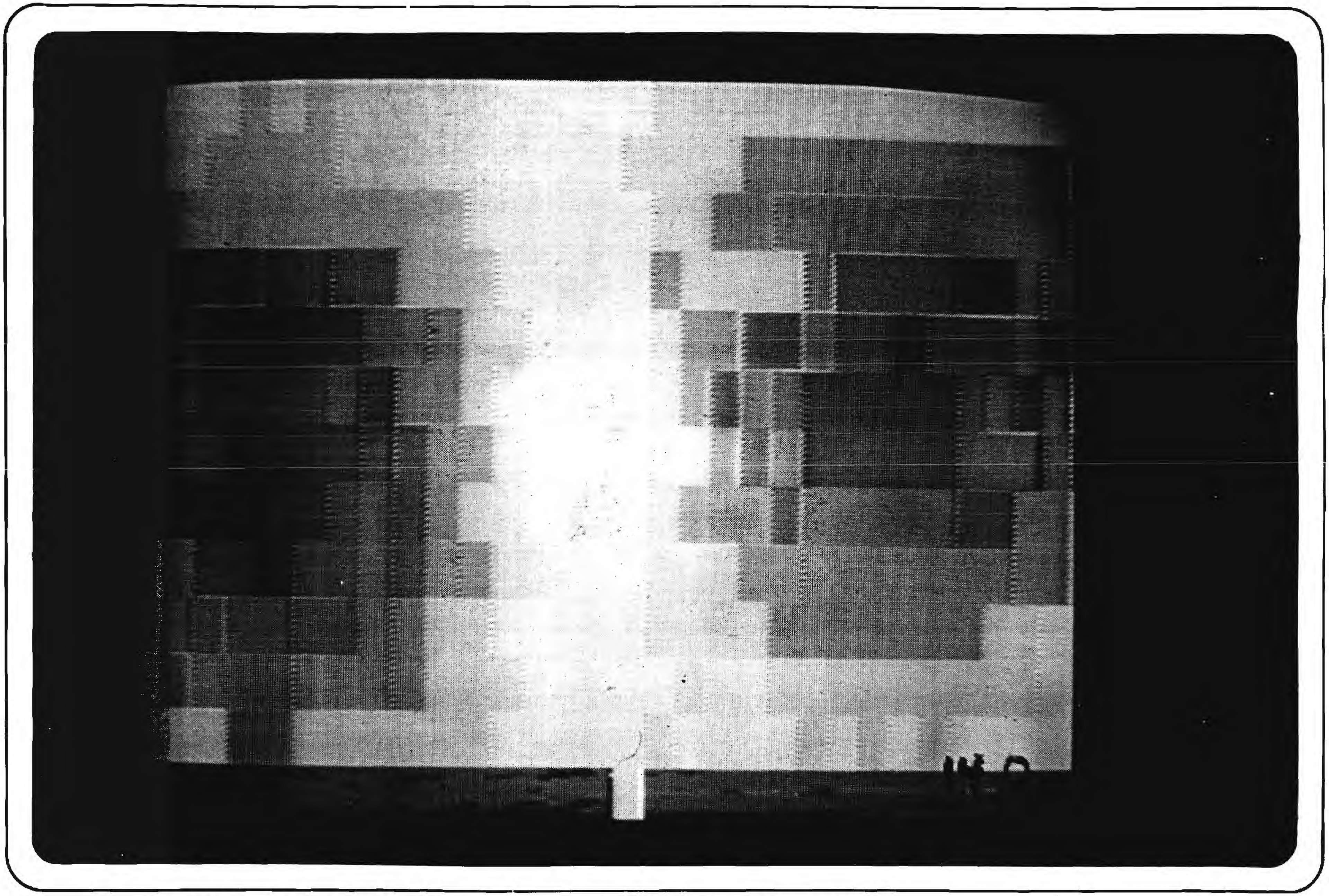


Figure 15. 95 GHz Radiometric Image for Run #14, Channel #0 with Reference Target on Left and ET Target (Dry) on Right.

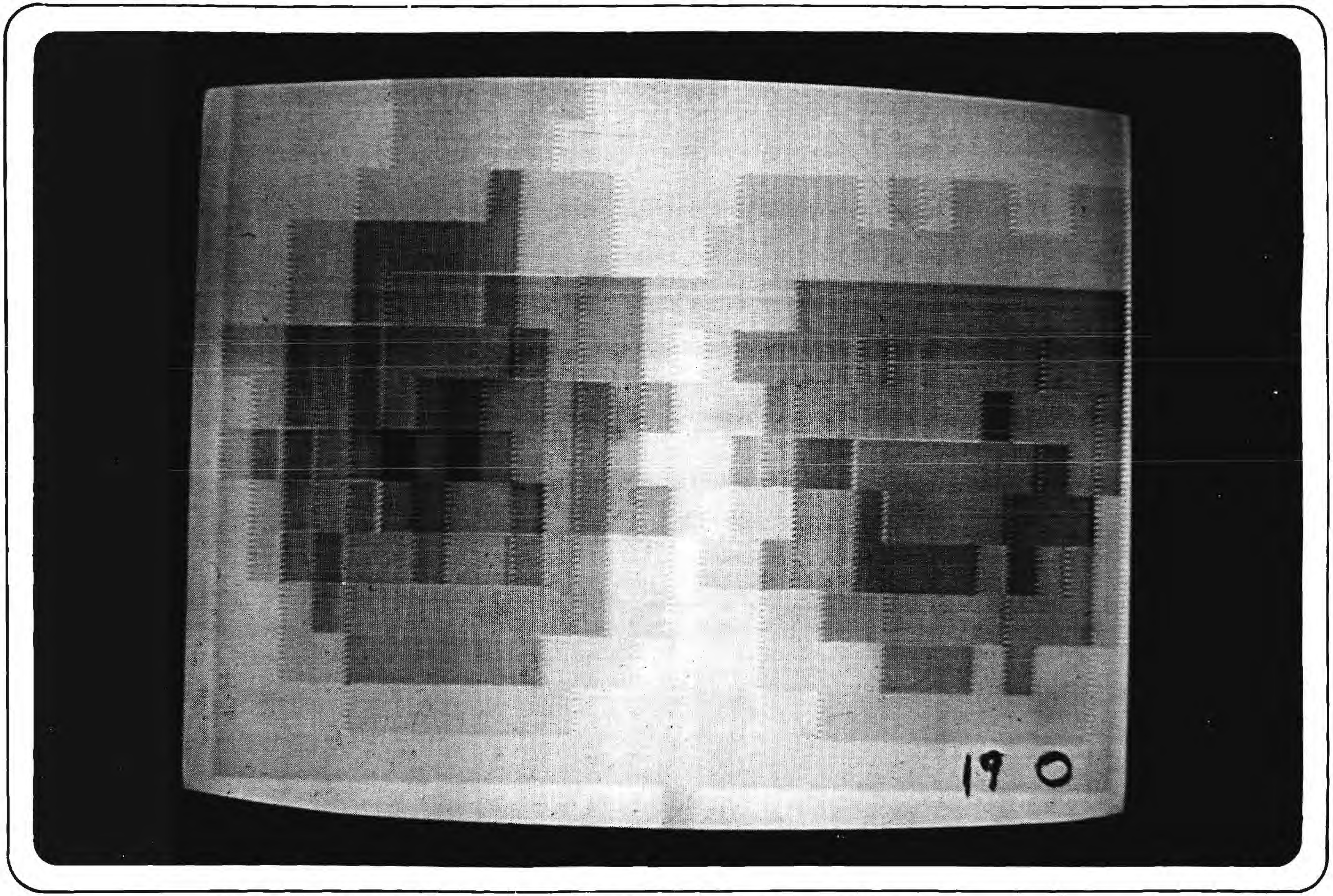


Figure 16. 95 GHz Radiometric Image for Run #19, Channel #0 with Reference Target on Left and ET Target (with Ice) on Right.

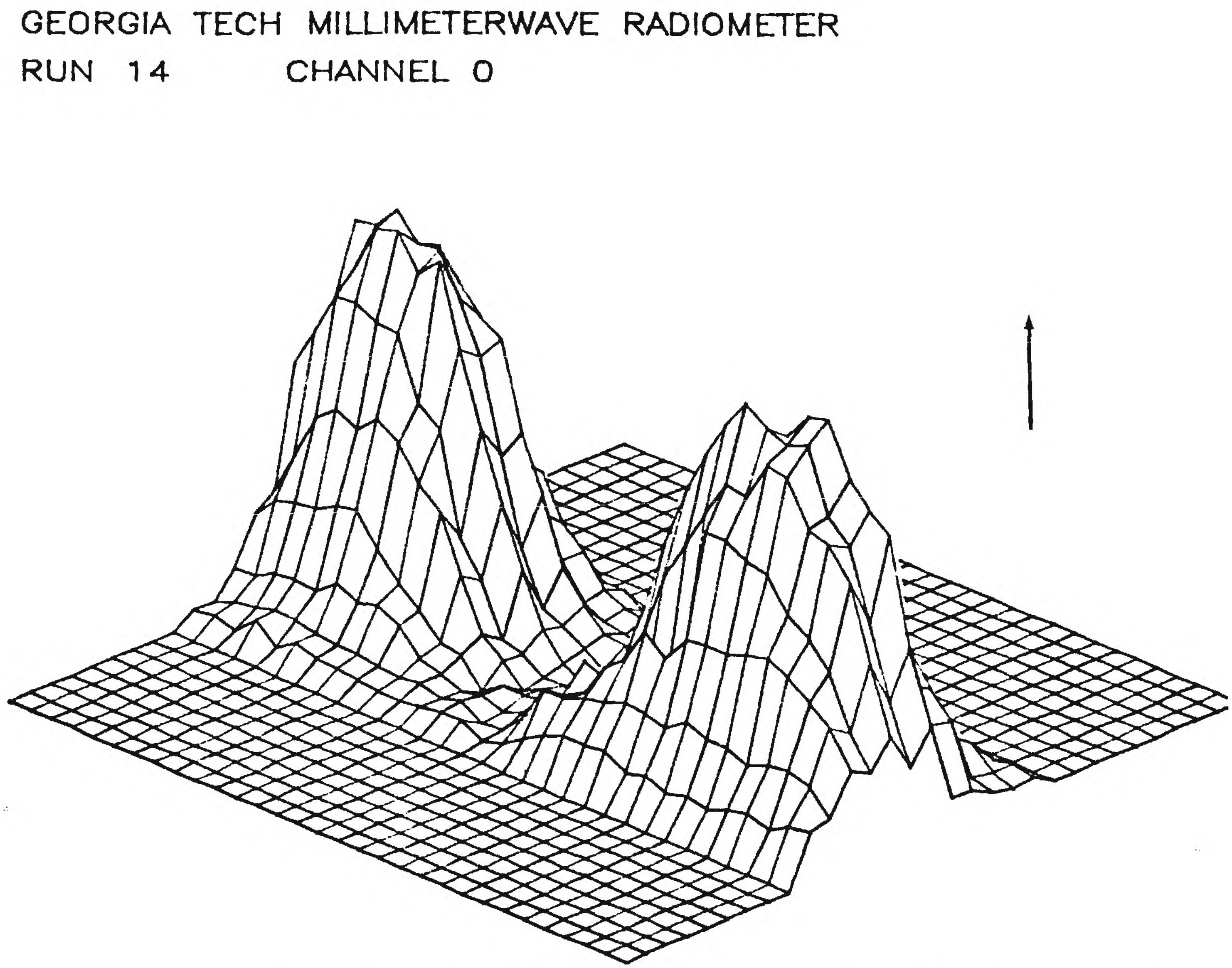


Figure 17. 95 GHz 3D Plot with Reference Target on Left and Dry ET Target on Right.

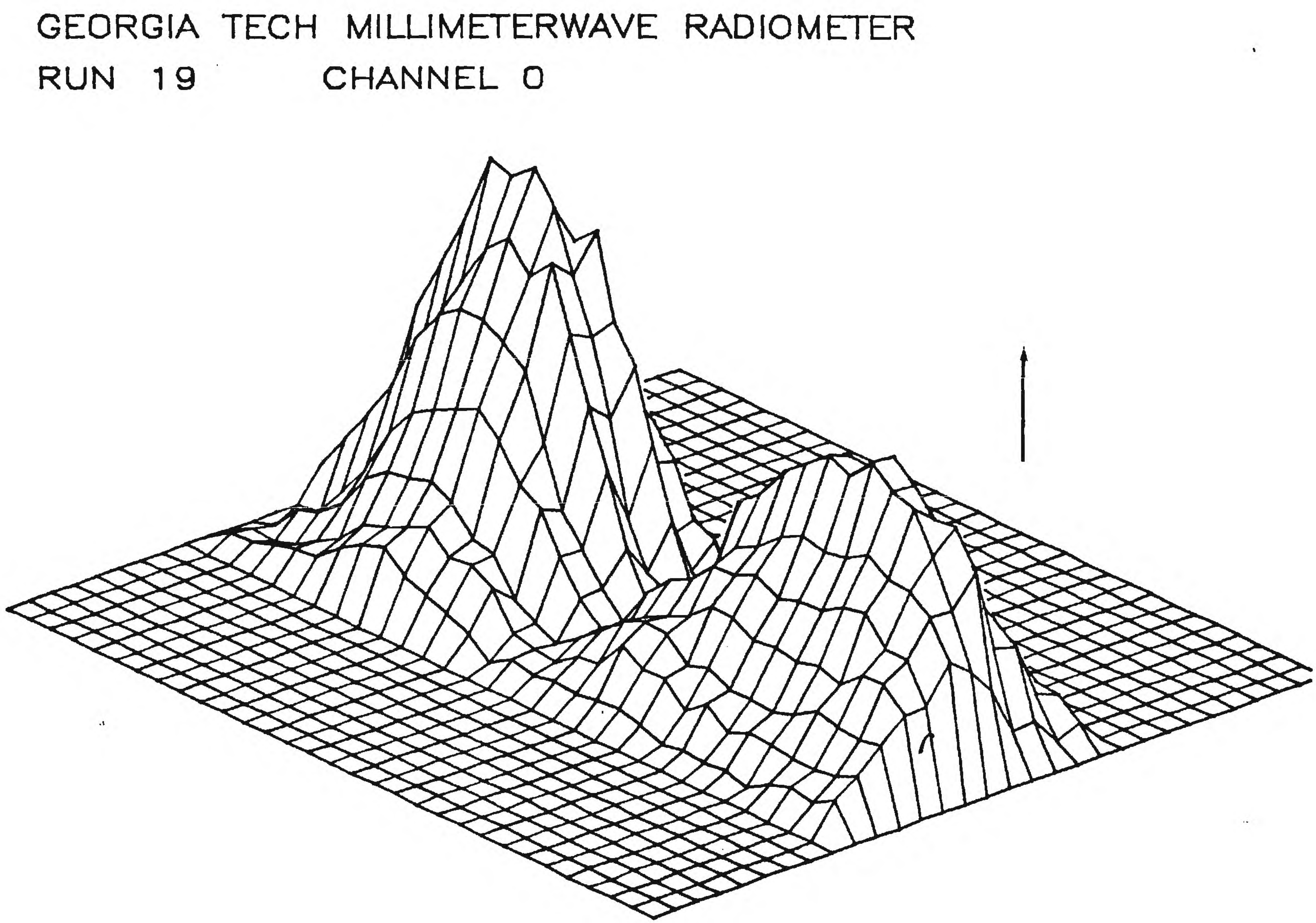


Figure 18. 95 GHz 3D Plot with Reference Target on Left and Ice Covered ET Target on Right.

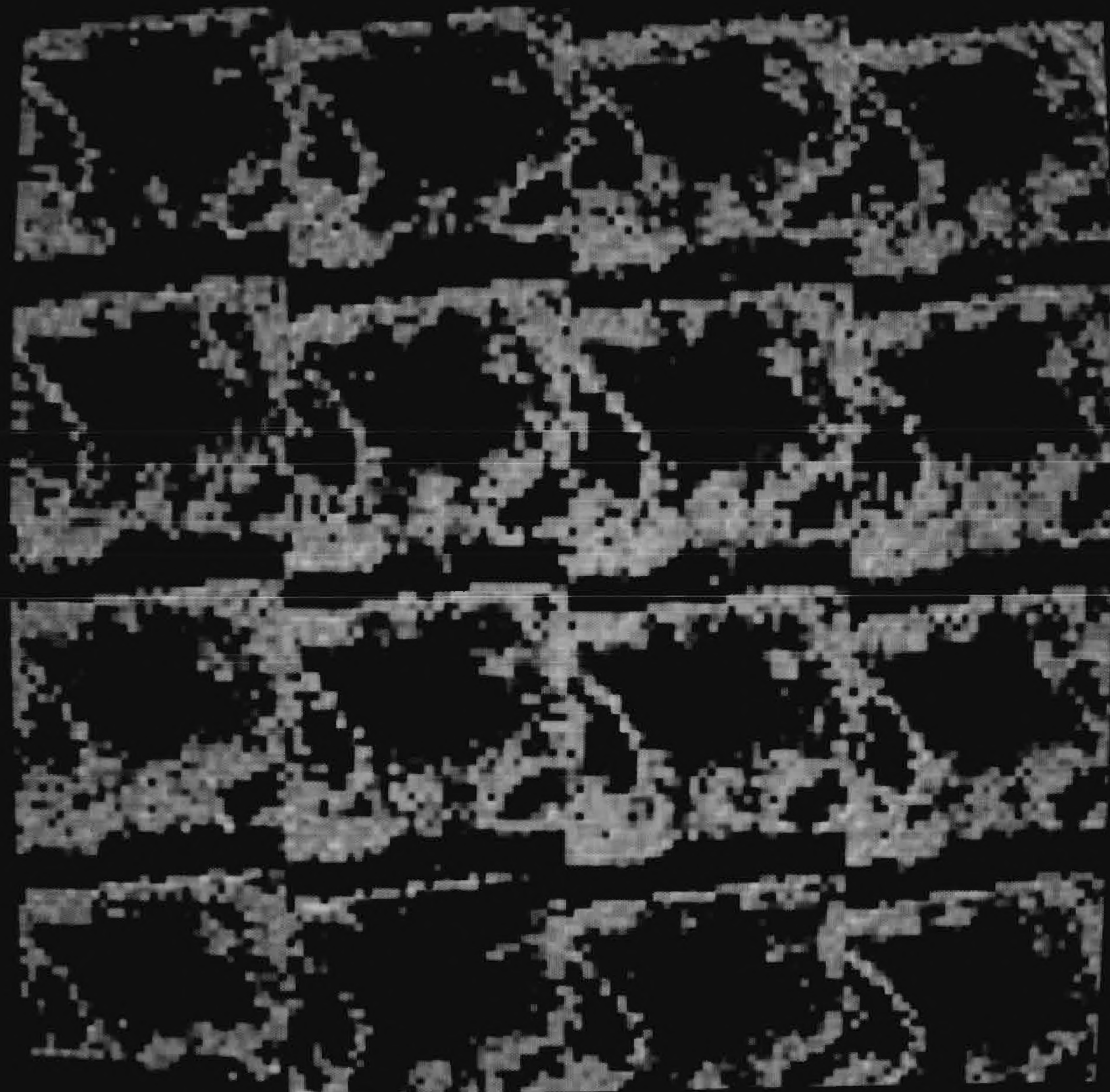


Figure 19. 95 GHz Imaging Scan Sequence of Shuttle ET at NSTL.

Table 7

95 GHz Radiometric Imaging Scan Sequence for ET During Cryogenic Loading Procedures

Scan(s) Note 1	Description
1&2	ET Pre-loading Scans
3&4	ET Loading Scans
5-8	ET Loading/Post-Loading Scans
9	ET Post-Loading Scan
10	Ice Artifically Form on Cut-out
11&12	Ice on Cut-out
13	Engine Firing During Scan
14-16	ET Scans After Engine Firing

Note 1. Scan sequence as follows (see Figure 19).

1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16

individual scan from pre-load to post-fire. During scan 10, ice was artificially formed on the cut-out area after the ET was fully loaded with cryogenics. Observe in Figure 19 that the cut-out area image shows a more reddish color which represents an increase in radiometric temperature. Detailed analysis revealed an increase of about 20°K due to ice formation on the ET which indicated a reduction in the cold sky reflection off the surface of the cut-out area.

Data analysis routines for the mean, standard deviation, and the variance of the NSTL ice signature data were developed during this program. Emphasis was placed on that data gathered during the January 1981 NSTL tests where ice signatures were collected from the cut-out area on the ET. Figure 20 is the view of the ET LOX section with selected portions of the ET target as shown. Locations of interest within the radiometer's scan pattern are further described in Table 8. Section 11 is the cut-out area with reduced foam thickness. The cut-out area is contained within the larger area designated as 9. Table 9 illustrates an example of the ice signature statistical data available. Data run #149 was the last 30 minute scan performed prior to the artificial formation of ice on the ET cut-out region. Data run #150 was the following scan which included the presence of ice. An increase in radiometric mean temperature of approximately 20K from run #149 to #150 on the sections 9 and 11 is evident from Table 9. Visual inspection during the NSTL tests revealed that ice was present on the cut-out section resulting in an apparent warming in the radiometric temperature.

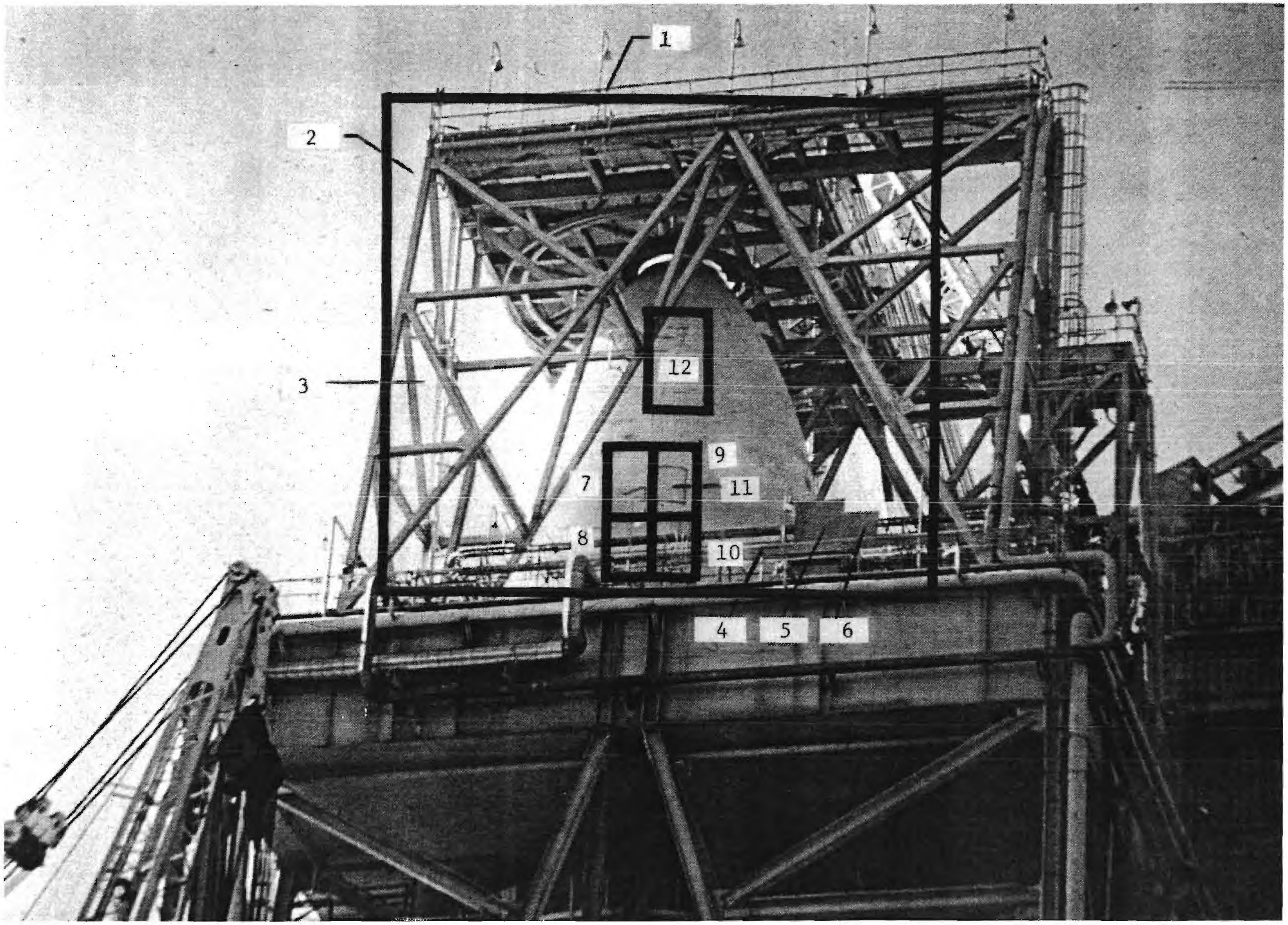


Figure 20. View of ET LOX Section at NSTL as Seen by 35/95 GHz Scanning Radiometer. (Refer to Table 8 for section call out.)

Table 8

Specified Areas Within the Radiometer's Scan of the NSTL ET LOX

Section(s)	Description
1	33 pixel by 33 row scan of LOX tank and surroundings
2	Sky view with minimum structure blockage
3	Sky view with partial structure blockage
4	Rail structure on stand beneath reference targets
5	Metal reference target
6	SOFI reference target
7,8	Sections adjacent to foam cut-out region
9	Section containing SOFI cut-out area
10	Area beneath cut-out region
11	SOFI cut-out (foam reduced to 1/2 inch thickness)
12	Upper portion of LOX tank

Table 9

NSTL Data Runs (Scans) #149 and #150 from 95 GHz
Vertical Polarization Radiometric Data Output

SECTION	TL COORDS		LR COORDS		NPTS	MEAN	VARIANCE	STD DEV
1	0,	0	32,	31	1056	145.2	839.3	28.97
2	0,	0	5,	2	18	74.3	321.1	17.92
3	1,	18	4,	21	16	104.9	221.1	14.87
4	21,	29	33,	32	52	187.5	260.8	16.15
5	25,	22	27,	26	15	98.2	251.2	15.85
6	28,	23	29,	26	8	104.4	464.3	21.55
7	12,	20	14,	24	15	149.0	37.5	6.13
8	12,	25	14,	29	15	152.1	128.9	11.35
9	15,	20	17,	24	15	130.4	155.7	12.48
10	15,	25	17,	29	15	146.0	388.3	19.70
11	15,	22	17,	23	6	124.1	123.8	11.13
12	15,	10	18,	15	24	186.3	26.0	5.10

a) RUN 149 CHANNEL 0
TH= 333.10 TC= 80.51 TSKY= 29.21 TLEN= 276.25
SCENE SIZE IS 33 PIXELS BY 33 ROWS
MIN AND MAX TEMPS ARE : 47, 212

SECTION	TL COORDS		LR COORDS		NPTS	MEAN	VARIANCE	STD DEV
1	0,	0	32,	31	1056	147.6	811.0	28.48
2	0,	0	5,	2	18	71.7	150.2	12.25
3	1,	18	4,	21	16	108.0	216.1	14.70
4	21,	29	33,	32	52	187.5	184.1	13.57
5	25,	22	27,	26	15	101.2	354.1	18.82
6	28,	23	29,	26	8	111.2	173.0	13.15
7	12,	20	14,	24	15	148.8	79.1	8.89
8	12,	25	14,	29	15	156.6	87.5	9.36
9	15,	20	17,	24	15	148.3	36.0	6.00
10	15,	25	17,	29	15	154.4	98.2	9.91
11	15,	22	17,	23	6	144.0	8.3	2.88
12	15,	10	18,	15	24	186.0	42.6	6.53

b) RUN 150 CHANNEL 0
TH= 333.12 TC= 80.51 TSKY= 29.63 TLEN= 277.49
SCENE SIZE IS 33 PIXELS BY 33 ROWS
MIN AND MAX TEMPS ARE : 42, 205

TH = hot calibrate load (^{o}K)
TSKY = sky temperature (^{o}K)
MIN and MAX Temps = minimum and maximum temp. (^{o}K) for run
NPTS = number of sample points in section
TC = cold calibrate load (^{o}K)
TLEN = antenna lens (^{o}K)
TL COORDS, LR COORDS = top-left and lower right coordinates for each section
MEAN = section mean temp. (^{o}K)
VARIANCE, STD DEV = variance and standard deviation (^{o}K) for section

5.0 Conclusion

The tests at Georgia Tech and at NSTL as well as the follow-up data analysis programs have proven the usefulness of millimeter wave radiometry techniques for the detection of ice formation on the shuttle external tank. The measurements revealed that ice on the ET resulted in an increase in the radiometric temperature of the ET surface due to reduced sky reflection from the target. Following these tests Georgia Tech modified the instrumentation radiometer by replacing the 20 inch lens with a 4 foot dish antenna. Figure 21 is a photograph of the modified radiometer. This change was performed to provide a smaller beam spot size for improved spatial resolution. Table 10 provides information on the instrument's capabilities for target detection for range $R \geq 450$ feet. The target range shown is consistent with information from NASA on sensor to ET target distances anticipated at the space shuttle launch facility.

The data analysis programs generated by Georgia Tech demonstrated that on-line processing of ice signatures collected during shuttle pre-launch operations could be used to aid NASA in determining a go or no-go launch. Follow-up measurements with improved spatial resolution would offer additional evidence of the usefulness of millimeter wave radiometry to support the ice detection measurements for the shuttle launch program.

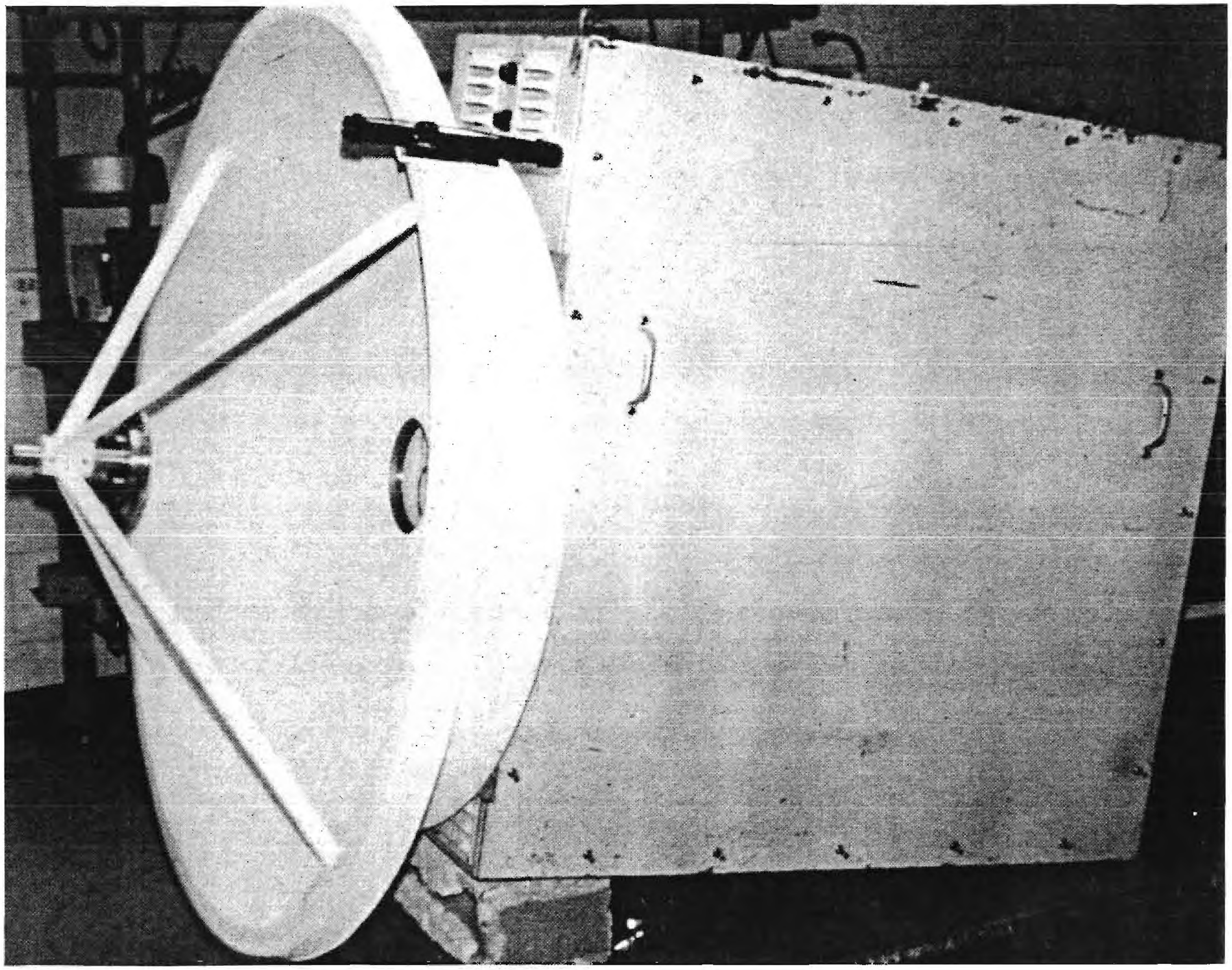


Figure 21. Georgia Tech 35/95 GHz Instrumentation Radiometer with 4-Foot Dish Antenna.

Table 10

95 GHz Radiometer Spatial Resolution Data Using 4-Foot Antenna Dish (Note 1)

R(ft)	d(ft)	$A_T(ft^2)$
450	1.728	2.345
500	1.920	2.895
550	2.112	3.503
600	2.304	4.169

Note 1. $d = R\theta°(\frac{\pi}{180})$, for $\theta° = 0.22$ degrees and $A_T = \frac{\pi d^2}{4}$.